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THE ERUPTIVE ROCKS

OF

ELECTRIC PEAK AND SEPULCHRE MOUNTAIN, YELLOWSTONE NATIONAL PARK.

BY

JOSEPH PAXSON IDDINGS.

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THE ERUPTIVE ROCKS OF ELECTRIC PEAK AND SEPULCHRE MOUNTAIN, YELLOWSTONE NATIONAL PARK.

By Joseph Paxson Iddings.

INTRODUCTION.

For the student of igneous or eruptive rocks there is no question which excites greater interest, and the correct answer to which would be of greater importance, than that involving the relation or connection between the various forms and kinds of coarse grained rocks and the different varieties of glassy ones. Any group of observations, therefore, that bears upon this problem should be studied with the greatest care, in order that we may learn how far it contributes to our understanding of these intricate relations, which not only lie at the foundation of any system of classification of igneous rocks, but which must affect our comprehension of the real nature of the rocks themselves.

The observations recorded in the following pages appear to contribute so largely to certain phases of the problem that it is hoped they may be presented in such a manner that the reader will be able to judge whether the conclusions arrived at by the writer are sufficiently well founded.

This study forms a part of the work undertaken by the division of the U. S. Geological Survey under the charge of Mr. Arnold Hague, which has been investigating the region of the Yellowstone National Park. It constitutes a chapter of the contributions which are being made from time to time to the knowledge of this highly attractive region, where the character of the country is so diversified that the student is confronted by nearly every phase of geology, among the most prominent of which are the phenomena of volcanic action, including the distribution and character of the volcanic material, the physics and chemistry of the thermal springs, and the dynamics of erosion and glaciation—problems which are being investigated by different members of the division. The present paper deals with a group of eruptive rocks occurring at Electric Peak and Sepulchre Mountain, which has been studied with special care because of the bearing of the results upon the general petrological question already stated.

The eruptive rocks of Electric Peak and vicinity embrace a group of *intrusive* rocks that occur in the form of a stock with apophyses, breaking up through Cretaceous strata, which had already been penetrated by horizontal sheets of intrusive rocks from a neighboring center of eruption. They also include a group of *extrusive* or volcanic rocks, lying east of Electric Peak, which form the mass of Sepulchre Mountain and contain certain intruded bodies.

The object of the present paper is to describe the nature and occurrence of these intrusive and extrusive bodies and to trace the geological and lithological connections between them, and to show the development of crystallization and the resulting mineral constitution of magmas of similar chemical composition which have solidified under a variety of physical conditions.

GEOLOGICAL SKETCH OF THE REGION.

In order to obtain a clear idea of the geological relations between the various groups of eruptive rocks coming within the scope of this paper, it will be necessary to sketch briefly the leading features of the geology of the region; the more so since the connection between the intrusive and extrusive bodies must be traced across a profound fault, which has affected a large area, and has permitted subsequent erosion to expose deeply seated intruded bodies by the side of contemporaneous surface extrusions.

Electric Peak, 11,100 feet in altitude, lies on the northern boundary of the Yellowstone National Park, 10 miles from its western line. It is the highest point of that portion of the Gallatin Mountains situated within the Park limits. These mountains have been carved out of a block of sedimentary strata composed of limestones, shales, and sandstones of Paleozoic and Mesozoic age, which range from Cambrian to Cretaceous. This block, about 14 miles wide, at present occupies the trough between two great bodies of Archean rocks, and trends northwest and southeast. It has been subjected to a succession of dynamical forces, which have bent it into a general synclinal fold, the axis of which lies near the northern body of Archean, and trends northwest and southeast. They have also produced a number of smaller transverse folds and faults with a nearly north-northeast and south-southwest trend.

The general synclinal movement was accompanied by a series of intrusions of igneous rocks, which found their way between the sedimentary strata, wherever the fissile character of the beds presented planes of least resistance to the dynamical forces engaged in bending them. These intruded masses formed immense laccolites and thinner sheets, that penetrate the more fissile strata for miles, with only occasional changes of horizon.

One large body of eruptive rock is located about 4 miles southwest of Electric Peak, and appears to have been the source of a great number of the sheets, which are intercalated between the Cretaceous shales

and sandstones of this mountain. As a result of the main synclinal movement the strata at Electric Peak have a general dip toward the northeast.

After the intrusion of the eruptive sheets a more local synclinal break occurred in the neighborhood of what is now Electric Peak, its axis trending northeast and southwest. The southeastern side of the fractured mass suffered the greater displacement, the strata being turned up vertically in some places. This break produced one or more large fissures and numerous smaller crevices, along which igneous rock was again forced through the shales and sandstones, in the form of a stock and dikes. The stock is located near the axis of the break, and the dikes, which are mostly vertical, branch out into the sedimentary beds for a short distance, and cut across the intruded sheets or cut between them where they had been previously turned up on end.

The igneous magmas which accompanied the convulsive movements of the ruptured strata and forced their way between them to cool as intrusive bodies, also reached the surface of the earth in places and took the form of extrusive masses. The ejected rocks were probably erupted from a number of different vents whose position was governed by the nature and extent of the fissures in the sedimentary rocks. They poured out as flows or massive eruptions and were subsequently blown to pieces and thrown into breccias and were occasionally cut by dikes. They undoubtedly formed very extensive bodies of volcanic ejectamenta which covered a large area of country.

After the intrusion of the stock and dikes just mentioned, and after the accumulation of the volcanic breccias, the region was broken by great faults. These faults trend nearly north and south and have caused great changes in the relative vertical position of the severed rocks, so that, after extensive erosion, deep-seated strata and intrusive bodies of erupted rocks are now exposed by the side of extravasated surface lavas.

The great erosion which carved the faulted blocks into the steep mountains and valleys of the Gallatin Range was followed by the eruption of the vast flows of rhyolite and less abundant basalt that form the plateau country to the south, since which time glaciation and erosion have still further modified the contour of the country.

ELECTRIC PEAK.

GEOLOGICAL DESCRIPTION.

The form and character of Electric Peak may be seen from the accompanying map and illustrations. The peak constitutes the highest point on the mountain ridge that stretches from Cinnabar Mountain to Mount Holmes. It is not an isolated mass, but is the most prominent portion of a range of mountains which present a continuous series of sedimentary strata. For the purposes of the present paper it will not be nec-

essary to explain more of its geology than may be included in the statement that the mass of the mountain from the streams which bound it on the south and west is made up of Cretaceous shales and sandstones, the lower portion being mostly black shale with occasional beds of sandstone, the upper portion being mostly sandstone with occasional beds of shale. The south and west slopes of the mountain are largely shale, and the summit and the top of the northeast spur are sandstone. These beds pass uninterruptedly into the broad ridge, which is north of the peak, and are well exposed on the south face of the spur that lies on the north side of the deep gulch northeast of Electric Peak. The south face of this spur and the pitch of the strata are shown on the right-hand side of the panorama of the mountain taken from Sepulchre Mountain. (Pl. XLVI.)

The southeast spur is formed by the upturned beds east of the synclinal already mentioned. At its extreme southern end the upper portion of the Carboniferous rocks is exposed, together with the Jura-Trias. The black shales have been metamorphosed in the vicinity of the main body of intrusive rocks, and have been indurated to such an extent that they have withstood erosion sufficiently to form the pyramidal mass of the southeast spur, which is to the left of the gulch in the center of Pl. XLVI.

On the south and west erosion has cut down 3,000 feet below the summit of the mountain, while on the east and northeast it has cut 4,000 and 5,000 feet below the highest point. Two deep gulches penetrate the very heart of the mass and lay bare its structure. Along the eastern base of the mountain the deeply cut drainage channel of Reese Creek marks very nearly the line of faulting that separates the rocks of Electric Peak from those of Sepulchre Mountain. The fault line passes across the slope just west of the main creek and up the south branch of the creek to the divide near Gardiner River.

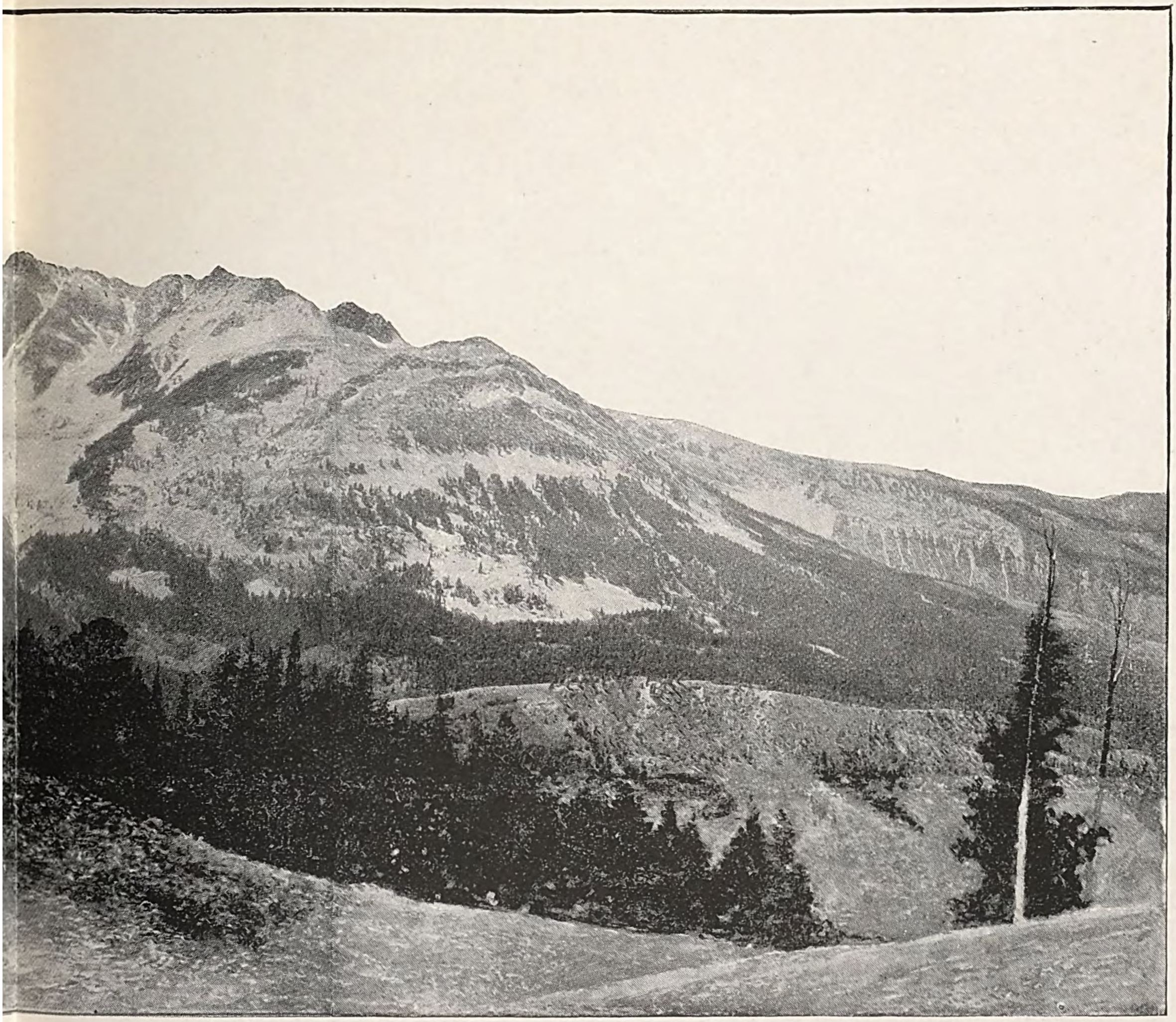
The character of the western half of the mountain is very different from that of the eastern, which comprises the eastern summit with the northeast and southeast spurs. The western and southern slopes are quite uniformly steep or precipitous exposures of slightly tilted strata with intercalated sheets of intrusive rocks, or long talus slopes of small fragments. The eastern summit and spurs, on the other hand, are irregular in form and present a serrated mass of crags and pinnacles with precipitous faces of rock hundreds of feet in height. The southern portion of the southeast spur, however, is more uniformly eroded to smooth slopes. The northeastern spur is especially rugged, and bristles with rocky points and needles. These features appear in Pl. XLVI.

This difference of character results from the change in the geological structure of the mountain. The shales and sandstones in the eastern portion have been highly indurated and altered, and, with the vertical dikes and stocks that traverse them, have withstood erosion much better than the unaltered strata to the west, and have presented a much more heterogeneous body, which has yielded very irregularly.

U. S. GEOLOGICAL SURVEY



ELECTRIC PEAK, FROM



OM SEPULCHRE MOUNTAIN.

The deep east gulch has cut an amphitheater at the base of the peak, which rises nearly 1,500 feet vertically above the débris in the head of the gulch. The walls of this gulch are shown in the panorama (Pl. XLVII) and its general position in the previous view. The gulch crosses the synclinal break and the main stock of igneous rock, but the great accumulation of angular débris, which fills the head of the gulch, obscures the bottom rocks. The central body or stock of intrusive rocks is located on the northeast spur of the mountain, where it has broken up into the upper sandstones. It outcrops in a great number of exposures which cover the southern slope of the spur from an altitude of 9,000 to 10,000 feet. A large branch stock runs up the crest of this ridge, forming the line of dark colored pinnacles shown on the right-hand side of the illustrations. It thins out before reaching the summit of the mountain. The southwestern end of the main stock is exposed in the south wall of the amphitheater already mentioned, left-hand end of the view (Pl. XLVII). It appears as a high wedge of crystalline rock reaching to within a few hundred feet of the top of the cliff, which is the north face of the pyramidal southeast spur. The crest of this spur, from an altitude of about 10,000 feet up to the summit of the peak, is serrated by numerous narrow gulches and rocky points formed by the weathering and erosion of a great number of narrow dikes and upturned intrusive sheets. The dikes are nearly vertical and are specially abundant along that part of the spur lying between the wedge of crystalline rock and the break in the sedimentary strata. They are less numerous as the summit of the peak is approached, and do not appear to occur farther to the northwest. They do not occur along the east base of the southeast spur, but extend southward across the upper slopes of the spur in parallel walls that rise above the shales. They are hardly to be distinguished from the upturned sheets, which, however, usually exhibit signs of crushing and displacement. They are very prominent where the shales are but slightly metamorphosed and are easily eroded. Toward the more indurated portion of the spur they are less noticeable and do not rise above the surface of the surrounding rocks. They become more numerous and larger toward the north as the area of metamorphism is approached.

The dikes appear to radiate from a center, situated on the northeast spur, where the main stock is located, and are confined to a range of about 45° from south to southwest. They are not more than a mile and a half long.

GEOLOGICAL MAP.

The geological map, Pl. LIII, exhibits the chief features of the geology in as simple a manner as possible. Owing to the small scale of the map and the necessarily limited time devoted to the study of the region, it is not possible to give more than a general idea of the geological structure of Electric Peak. Only a small number of the intruded sheets of igne-

ous rocks can be represented and their thickness has to be exaggerated. Thus ten sheets are represented instead of fifty, and they are drawn 50 to 150 feet thick, while in actual fact they are from 4 to 30 feet thick. Moreover, the sheets are continuous, following the bedding of the strata for long distances, and breaking up toward the north and east into higher layers which they follow in turn; occasionally the sheets intersect one another. On the map, however, they are not drawn continuously, but are interrupted, as there are not sufficient data to carry any one sheet a very long distance. The same is true of the dikes, which are more numerous and narrower than they are represented on the map.

The sedimentary rocks are colored according to the period in which they were deposited, that is, as Carboniferous, Jura-Trias, and Cretacous, without attempting to express any further subdivisions. The large accumulations of morainal débris in the east and northeast gulches are represented. They are made up of large angular blocks of the sedimentary and eruptive rocks in which the gulches are located.

That portion of the map which represents the structure of Sepulchre Mountain will be understood when the geology of this locality is described.

THE ERUPTIVE ROCKS OF ELECTRIC PEAK.

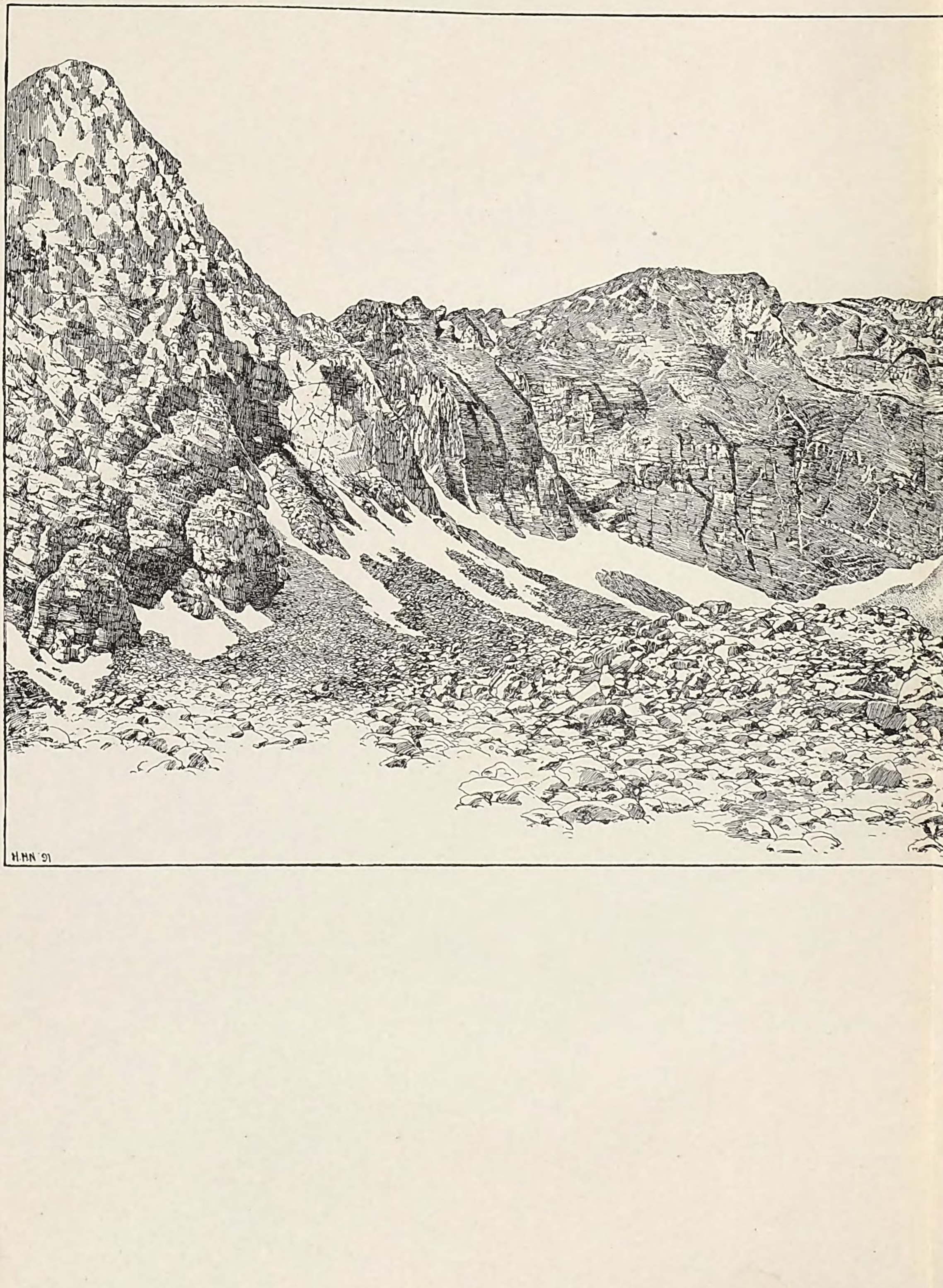
The igneous rocks that form the intruded sheets, and the subsequent stock and dikes, comprise a number of varieties, having quite an extended range both of composition and of structure. They include modifications of diorite and porphyrite, the extreme forms approaching granite and quartz-porphyry.

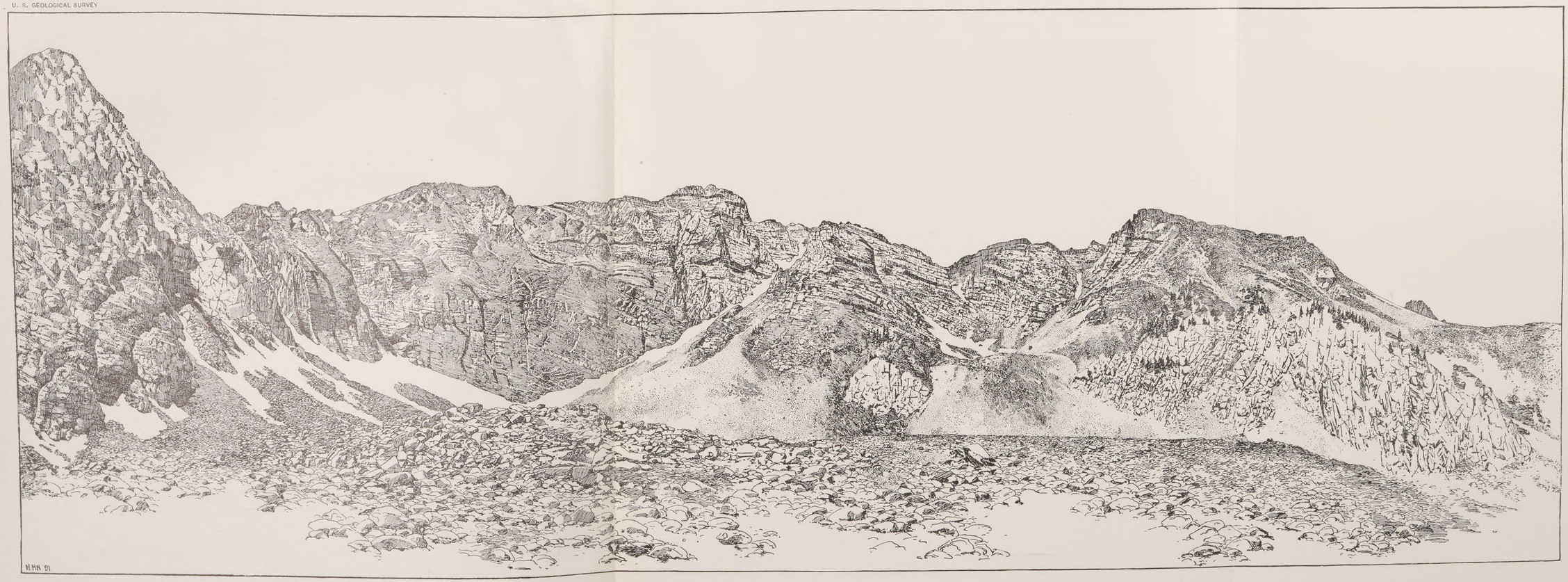
Before entering upon the description of these rocks it will be necessary to explain at some length the writer's use of the terms *porphyrite* and *porphyry* in order to avoid a possible misunderstanding.

USE OF THE TERMS PORPHYRITE AND PORPHYRY.

The term *porphyrite* is used throughout this paper for certain structural forms of rocks whose essential minerals include the lime-soda-feldspars, while the term *porphyry* is used for the corresponding structural forms of rocks characterized by the alkali-feldspars. This is the same usage as that adopted by Prof. Rosenbusch in his "Mikroskopische Physiographie der massigen Gesteine." Stuttgart, 1886, p. 301. In limiting the usage of these terms to certain structual forms of igneous rocks the writer wishes to call attention to the freedom of the terms from any implication of the age of the rocks. In this respect Prof. Rosenbusch appears to have fallen into a seeming inconsistency, since he subsequently confines the terms *porphyrite* and *porphyry* to the paleovolcanic equivalents of the neovolcanic andesites, dacites, rhyolites, etc. This action can be consistent only on the assumption that the ancient and modern volcanic rocks in all cases differ from one another in structure, a supposition which is contrary to our present experience. With every step in the advancement of our knowledge of the geolog-

U. S. GEOLOGICAL SURVEY





HEAD OF EAST GULCH OF ELECTRIC PEAK.

ical occurrence of igneous rocks it becomes more and more evident that the magmas which were erupted in Paleozoic times crystallized into rocks which differed in no essential respect from those of recent date, though in the former instances they have more frequently suffered from decomposition and other modes of alteration. The apparent greater preponderance of certain forms of rocks in the earlier periods of the earth's history has been correctly referred to the effect of great denudation during long ages, and the consequent exposure of those portions of the solidified magmas that were situated at greater distances from the surface of the earth. Hence the apparent connection between the structure of these rocks and their geological age. In proving the absence of this supposed connection the use of an age qualification in the definition and classification of igneous rocks has been eliminated, while the distinctions due to their structure remain unchanged. The coarse grained forms of rocks that are characterized by labradorite, augite, and hypersthene, or by labradorite, hornblende, and biotite are none the less gabbros or diorites because they have crystallized in Tertiary times or lie incased in basaltic breccias. Neither should we give up the terms *andesite* or *rhyolite* because lavas of their composition and texture occur in older geological ages. For similar reasons, then, we should continue to use the terms *porphyrite* and *porphyry*, limiting them to certain structural forms, for which they were in most cases originally employed. In the present paper they are applied to medium grained porphyritic rocks that occupy an intermediate position between the coarsely granular diorites and gabbros, and the microlitic or glassy andesites. This, we think, corresponds the most closely to their earliest usage.

It is to be further remarked that the terms *porphyrite* and *porphyry* are applied to rocks without reference to their state of preservation, though, of course, their best types are perfectly fresh, unaltered rocks. There are abundant instances in which igneous rocks of recent date exist in a perfectly fresh and unaltered condition, without evidence of any change having taken place within them since they crystallized from a molten state, except occasional surface weathering. Such a set of rocks are those described in this paper. They present all degrees of microstructure, from the finest to the coarsest; the medium grained forms are inseparably connected with the glassy lavas on the one hand and with the coarsely granular rocks on the other. Their crystallization is not the devitrification of previously solidified glass, but is the crystallization of a heated fluid magma. It is in this sense *primary*. It is a fair presumption that the majority of magmas that have crystallized into an association of silicate minerals retain their original structural character for a very great length of time, geologically speaking, unless subjected to dynamical or chemical processes which rearrange their mineral constituents more or less completely. Where this has taken place there are usually evidences of the fact, either within the

rock itself or in those surrounding it. Instances of the devitrification of solidified glasses are abundant and have been ably studied and interpreted, especially by the English petrographers. It seems to the writer, however, that the utmost caution should be exercised in treating such altered rock bodies, since it may not be possible in most cases to discover exactly what was the primary condition of the rock before alteration set in, and a primary crystalline structure may be mistaken for a secondary one. The writer is not aware from personal experience, that the two can be distinguished in most cases even. Differences between the two, however, are to be expected, and both should be carefully studied together. It is certain that very many structures common to glassy rocks, such as lithophysæ and other crystalline cavities, must be highly modified by any process of secondary alteration. In many cases the altered forms of igneous rocks can be distinguished from their primary, fresh condition. It is to the unaltered forms of the medium grained porphyritic rocks that the terms *porphyrite* and *porphyry* have been applied in this paper, which appears to the writer to be their legitimate use. He would, therefore, urge those who have restricted the term porphyrite to altered andesite to restore it to its original application in order that the porphyries or porphyrites of petrography may correspond to the porphyries of more general usage.

SHEET ROCKS.

The rocks occurring as intrusive sheets present a series of fine grained holocrystalline forms of porphyrite and a variety of diabase. They are all more or less porphyritic, but vary somewhat in habit from coarsely porphyritic to those in which the porphyritic structure is scarcely noticeable. In color they range from dark to light gray, which may be bluish, greenish, or brownish, according to the freshness or degree of alteration of the rock.

In the upturned strata of the southeast spur the sheets vary in thickness from 4 feet to 20 or 30 feet, and the rocks forming them often exhibit characters which indicate that what are now two vertical sides of the bodies were originally top and bottom surfaces of nearly horizontal sheets. Thus the two sides are often quite different. In one instance what was the bottom of the sheet is much darker colored than the body of the rock, which exhibits a strongly marked flow structure, while the side which was formerly the top surface bears large spherical nodules ranging from several inches to 10 inches in diameter. A still more striking difference between the two sides of an upturned sheet is found in a 30-foot sheet of augite-porphyrite or diabase, which occurs on the lower slope of the southeast spur and on the south side of the large east gulch. The rock is dense, massive, and greenish; near the east contact, which was originally the bottom of the sheet, it is very fissile and crumbles upon weathering, giving rise to a narrow gulch. Immediately at the contact with the shale it is dense and much altered,

with a purplish tinge of color. A layer of the sheet 4 or 5 feet thick near the bottom contact is full of large porphyritical augites. The remainder of the body to the western contact or upper surface does not contain them, but exhibits small feldspar phenocrysts and is more massive, and weathers quite differently from the coarsely porphyritic portion of the body. The presence of a broad band of rock carrying all the large phenocrysts and situated on one side of a vertical sheet of eruptive rock, could scarcely be accounted for if the body had been intruded vertically, unless it was assumed that there had been two intrusions of different magmas. But when it is found that the body was originally a nearly horizontal sheet, the presence of a layer near the bottom containing all of the large crystals of augite, while exceptional, is nevertheless in accord with the observations of Charles Darwin[1] upon the basaltic flows of the Galapagos Islands, and of Clarence King[2] upon the lava streams of Hawaii. Both of these observers mention instances in which the larger crystals had fallen to the bottom of small basalt flows, leaving the upper parts quite free from them. In these cases the magmas must have been very liquid.

The greater part of the sheet rocks that occur in the eastern part of Electric Peak and come within the present discussion are somewhat decomposed. This appears to be due to the dislocation and shattering which they have undergone at the time of the upturning of the strata containing them. On the southeast spur they usually exhibit slickensides and distinct evidences of crushing in conjunction with that of the shales in which they lie, the shales frequently showing a crumpled "cone-in-cone" structure near their contact with the sheet rocks. The latter have in this way been rendered more susceptible to the decomposing action of the atmosphere. In some instances the substance of the ferromagnesian silicates has been destroyed, leaving only the original form of the minerals recognizable. In general, however, the decomposition has not destroyed the feldspars nor materially affected the microstructure of the rock.

As the fresher and more extensive occurrences of these intrusive sheets will be fully described at another time, it is not necessary to enter into a detailed account of them in this paper. Considered mineralogically they comprise:

(*a*) Rocks whose essential minerals are lime-soda feldspar and pyroxene, with no hornblende.

(*b*) Rocks with lime-soda feldspar and pyroxene and some hornblende. These embrace a few doubtful occurrences which may be upturned sheets or vertical dikes.

(*c*) Rocks with lime-soda feldspar and hornblende with little or no biotite, and no pyroxene.

(*d*) Rocks like (*c*) with more biotite.

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[1] Volcanic Islands, London, 1851, p. 117.

[2] U. S. Geol. Expl. of the Fortieth Parallel, vol. 1, Systematic Geology, p. 715.

(*e*) Rocks with lime-soda feldspar, biotite, and hornblende, the biotite being in excess of the hornblende.

(*f*) Rocks like (*e*) with some quartz phenocrysts.

These variations in mineral composition are accompanied by changes in the character and amount of the feldspars. Toward the end of the series, in the order given, the feldspars become less and less basic, and more abundant, and are associated with an increasing amount of quartz, which appears microscopically in the groundmass of the rock. The ferromagnesian silicates necessarily diminish in amount from the hornblende end of the series toward the mica end.

The microscopical characters of the minerals in these rocks are similar to those of the dike rocks of like grain, which will be described later on. The groundmass has the same microstructure as that of the dike rocks, and varies in the degree of crystallization from microcryptocrystalline to microcrystalline.

By far the greater number of the sheets in Electric Peak are of hornblende-mica-porphyrite, without pyroxene or porphyritical quartz. Only two occurrences carry small quartz phenocrysts. The pyroxene-bearing varieties form an insignificant part of the group.

The sheet rocks having been intruded between the sedimentary strata prior to their steep upturning and to the vertical fracturing which admitted the material forming the dikes and main stock, it appears that the magma or magmas which took the form of sheets were characterized for the most part by phenocrysts of hornblende and biotite, and that on the one hand they pass into varieties bearing porphyritical quartz, and on the other hand they grade into forms bearing pyroxene. Hence they present varieties of rock which occur again as later eruptions in the dikes and stock.

DIKE AND STOCK ROCKS.

As already mentioned the igneous rocks occurring in the stock and its apophyses and in the dikes form a group of diorites and porphyrites of variable composition and structure. The greater number of the porphyrites and diorites are not separable, except in a general way, as they are connected by intermediate structural varieties. In general, the coarse grained and granular rocks, the diorites, are confined to the main stock and the larger apophyses, while the porphyritic finer grained rocks, the porphyrites, occur in the dikes and small apophyses and along the sides of the stock, in places, in contact with the sedimentary rocks.

The main body of the stock is diorite. It varies in structure and composition, the variations being rapid in some places and very irregular. There is ample evidence that a series of eruptions followed one another through this conduit or fissure. The nature of this evidence will appear when the rocks composing the stock are described in detail. A study of the porphyrites occurring as dikes and contact facies of the stock reveals the fact that most of them differ from the main body of diorite in the character of their porphyritical minerals, or those older minerals which were present in the magma at the time of its eruption.

Most of the porphyrites are characterized by the presence of idiomorphic hornblende and biotite, and by the absence of pyroxene. In some varieties of the diorite there is evidence of an early crystallization of brown hornblende, and of pyroxene, but none of biotite. In most of the diorite, however, there is no evidence of any development of phenocrysts.

If we consider what would be the course of events when a synclinal fracturing of sedimentary strata, as in the case of Electric Peak, permitted a series of molten magmas to be forced through the resulting fissures, we see that the first magma would penetrate all the small crevices connected with the larger fissures and fill them with its material, which would solidify rapidly as narrow dikes. The magma occupying the large fissures would remain molten much longer, consolidation setting in on the sides and in the narrower portions. A subsequent eruption would force the molten portion out and replace it by other material. It would also fill up any new crevices or fissures made at the time of its outbreak. But their number would probably be much smaller than that of the crevices accompanying the first great upheaval or dislocation of the strata. Hence the number of dikes of the same magma as that constituting the later eruptions would be smaller. The magma which eventually closed the conduit would be represented by but few dikes, unless the final outbreak had been accompanied by extensive fracturing and dislocation. At Electric Peak the last intrusion of magma was not a violent one, which indicates that the dynamical forces were gradually dying out in this vicinity. The latest magma to rise in this conduit was that of the quartz-diorite-porphyrite which broke through the middle of the diorite stock and filled six or eight narrow crevices stretching toward the southwest.

The rocks about to be described constitute a very complex group, since they are portions of a series of magmas that have followed one another with more or less interruption through the same conduit on their way to the surface of the earth, and have consolidated under different physical conditions. Their relations to one another are so intimate and their variations in composition and structure so gradual and so extensive that it is almost impossible to discover any simple method of presenting the facts regarding them. It will be necessary to treat them collectively, owing to their number, and also to consider them in different groupings and from different points of view.

For convenience of petrographical description and because the greatest number of similar varieties of rocks will be brought together, they will be treated in the following groups:

I. The greater number of dike rocks and some of the contact facies of the stock, that are older than the main body of the stock.

II. The main body of the stock, with most of its contact facies, and most of the rocks that have broken up through it, and some apophyses that appear to be contemporaneous with it.

III. The quartz-mica-diorite-porphyrite which has broken up through the main body of the stock, and has produced a few dikes.

1. THE DIKE ROCKS AND CERTAIN CONTACT FACIES OF THE STOCK.

Porphyrites.—The porphyrites forming the dikes, which are from 1 or 2 feet in width to 25 feet, have a generally uniform habit. They are dense, fine grained rocks, filled with a multitude of small feldspars and ferromagnesian silicates, mostly hornblende and biotite, which gives them a uniformly speckled appearance, with occasional spots of white feldspar or of black ferromagnesian silicates. The general habit is modified by a variation in the color of the rock, due to the relative abundance of the dark and light phenocrysts, and to the nature and amount of the groundmass. The color of the rocks varies from dark greenish and purplish gray to light gray of different tints. In the region of the metamorphosed sandstones some of the dike rocks have been bleached to white. The quartzose dike rocks will be described in connection with the quartz-mica-diorite-porphyrite in Group III (p. 617.)

In the field it is observed that some are very fresh and compact, others decomposed and disintegrated. They become rusted and weathered in much the same manner as the metamorphosed strata containing them, and are crossed by the same system of joints. For this reason they can not be recognized at a distance on the face of the cliff at the head of the east gulch.

When they are studied in thin sections under the microscope, they are found to consist of a holocrystalline groundmass, with abundant phenocrysts of lime-soda-feldspar and hornblende, generally with biotite and occasionally with pyroxene. Mineralogically considered, they constitute a series of varieties of porphyrite with a variable percentage of hornblende, biotite, and pyroxene, without any one variety being particularly predominant. They may be arranged in the following subdivisions according to the relative amounts of the various ferromagnesian phenocrysts:

TABLE I.—*Mineral variation of the porphyrites at Electric Peak.*

Subdivisions.	Biotite.	Hornblende.	Pyroxene.
a	much.	some.	.....
b	much.	much.	.....
c	some.	much.	.....
d	little.	much.	.....
e	.....	much.	.....
f	.....	much.	some.
g	.....	much.	much.
h	.....	some.	much.
i	.....	.....	much.

Besides the porphyritical biotite which crystallized previous to the eruption of the rocks, there is some that was evidently crystallized at the time of their final consolidation. The latter occurs in shreds and irregularly shaped individuals.

The microscopical character of the different minerals is much the same throughout the series, and no particular specimen will be described as

the type rock, for the variations throughout the series are gradual, and no single variety should be selected to represent the remainder. The variations affect the relative proportions of the minerals composing the rocks and their microstructure. A gradual modification of the species of the plagioclase feldspars may be detected by their optical properties, but a corresponding range of changes within the isomorphic series of the hornblendes, pyroxenes, or biotites is not recognizable, if it is present. The variation in mineral constitution affects the microstructure of the groundmass, an increase of quartz being accompanied by an approach to a granular structure.

In describing the porphyrites which belong to the nine subdivisions just given, it must be borne in mind that for each mineralogical variety there is a range of structural forms which depend on the crystalline development of the rock. In order to give an idea of these different varieties of porphyrite the general features of each will be described first, and afterwards the characteristics of the essential minerals.

(*a*) This variety, which is characterized by abundant phenocrysts of biotite, some of hornblende, and no pyroxene, constitutes a narrow dike, whose width varies from 10 inches to 10 feet. Specimens from its sides and the middle, at a place where it is 8 feet wide, show that the groundmass of the rock, near its contact with the inclosing rocks, is fine grained, being composed of irregular patches about $0{\cdot}04^{mm}$ in diameter. The patches are clouded with minute particles, which are partly shreds of mica and partly lath-shaped feldspar.

In the center of the dike the groundmass is made up of very irregular patches, from $0{\cdot}09^{mm}$ to $0{\cdot}43^{mm}$ in diameter. They are filled with lath-shaped feldspar microlites and minute gas cavities and carry microscopic hornblende and biotite. The patches are quartz, which has crystallized as the last mineral, and acts as a cement for those which preceded it. Its true nature is recognizable in still coarser grained forms of similar rocks, where it can be tested optically. The quartz forming a single patch has one orientation and behaves as an optically uniform individual, but the minerals inclosed in each patch of quartz have no uniform orientation. The structure is the same as the poicilitic structure of certain coarse grained rocks. It may therefore be called *micropoicilitic*, and is to be distinguished from micropegmatitic structure by the fact that in the latter case groups of the inclosed minerals have the same orientation throughout each group.

Through the groundmass are scattered abundant phenocrysts of lime-soda-feldspar from 1 to 2^{mm} long and smaller crystals of hornblende and biotite. The relative proportion of the hornblende and biotite is not constant, the biotite being in excess of the hornblende in some specimens of the rock and equal to or even less than the hornblende in others. The biotite preponderates in those specimens from this dike with the fewest ferromagnesian silicates. As the amount of the dark colored minerals increases the hornblendes increase. There is a little magnetite, apatite, and zircon.

(*b*) This is represented by a 4-foot dike just west of the summit of Electric Peak. It is fine grained, with the same micropoicilitic structure, the patches 0·05 mm in diameter. The rock is not entirely fresh, and the phenocrystic plagioclases and micas are somewhat altered, but the hornblendes are not so much decomposed.

(*c*) is represented by a 2-foot dike on the southeast spur. The groundmass is very fine grained, with a slightly micropoicilitic structure which is not well marked, and merges into one in which the lath-shaped feldspar microlites become more prominent. The hornblende is considerably in excess of the biotite.

(*d*) is represented by a 3-foot dike on the northeast spur, which is dark colored at the center, but along the contact with the metamorphosed sandstone is light colored, with fewer and more prominent phenocrysts. The groundmass is a fine grained aggregation of lath-shaped feldspars and irregular grains; there is much iron oxide; phenocrysts of hornblende and plagioclase are abundant; biotite is scarce.

(*e*) is represented by a narrow dike a quarter of a mile west of the summit of Electric Peak. The groundmass is very fine grained, composed chiefly of lath-shaped feldspars about 0·04 mm long, with some irregular grains, and considerable chlorite resulting from the partial decomposition of the hornblende. The phenocrysts of hornblende and feldspar are small; there is no mica.

In the foregoing varieties pyroxene is entirely absent, and the chief variations are in the relative proportion of mica and hornblende, and in the microstructure of the groundmass. The micropoicilitic structure appears in those fine grained rocks which have a certain amount of quartz. It is replaced by a "felt-like" structure in the more basic varieties of nearly the same degree of crystallization.

(*f*) is represented by a 10-foot dike on the southeast spur. The groundmass is fine grained, composed almost entirely of lath-shaped and rectangular plagioclases, about 0·07 mm long, with some irregular grains and microscopic hornblendes and shreds of biotite. There is but little iron oxide. The porphyritical plagioclases and hornblendes are abundant. There was probably a small amount of phenocrystic pyroxene, which has been altered to fibrous green amphibole. Biotite is present in shreds, but not as phenocrysts. It may have been formed during the final crystallization of the magma, but part of it appears to be secondary, due to the subsequent alterations of the rock.

(*g*) is represented by a contact facies of the main stock. The rock resembles the other varieties of porphyrite in its general habit and structure. The groundmass is fine grained and is made up of lath-shaped, rectangular, and irregularly formed plagioclases, about 0·15 mm long, besides some quartz, with microscopical hornblendes and biotites. The phenocrysts are hornblende and plagioclase in abundance, and much pyroxene which has been completely uralitized. There are no phenocrysts of biotite. Iron oxide, probably magnetite, is abundant. Apa-

tite and zircon, if present, are rare. The development of the porphyritical hornblendes is particularly interesting and is described on page 593.

(*h*) is represented by a much coarser grained variety, occurring as a dike, 10 to 15 feet wide, on the southeast spur. It is, however, but slightly porphyritic, consisting of a mass of lath-shaped plagioclases, 0·4^{mm} to 0·7^{mm} long, with very rarely a larger individual, 1^{mm} long. Between these is a very small amount of cementing material, composed of irregular grains of feldspar and quartz and ferromagnesian silicates, amphibole, and mica. There is much uralitized pyroxene and a small amount of primary hornblende, with some biotite. The latter appears to belong to the period of final crystallization of the magma and is possibly due in part to subsequent alteration. The largest idiomorphic minerals are the altered pyroxenes, so that the rock undoubtedly belongs to a magma which carried numerous pyroxenes and some hornblende at the time of its eruption.

(*i*) is represented by a 4-foot dike on the northeast spur. It is distinctly porphyritic; the groundmass of the central portion of the dike rock is fine grained, composed of lath-shaped plagioclase about 0·1^{mm} long, and irregular grains of feldspar, with very little quartz. It also contains shreds of biotite and microscopic amphibole, with some iron oxide. The groundmass of the rock from the side of the dike is finer grained, with the same general structure, but with no mica or amphibole; there is, however, much colorless monoclinic pyroxene in irregular grains, whose primary nature is questionable. The rock bears abundant phenocrysts of plagioclase and pyroxene, but none of hornblende or biotite. In the center of the dike the pyroxene has been completely altered to uralite, which is also scattered through the groundmass. Near the contact of the dike rock with the metamorphosed strata the pyroxene is an almost colorless monoclinic species resembling that which has resulted from an alteration of hornblende in other varieties of porphyrite from this region, to be described later on. It does not resemble the primary porphyritical pyroxenes which occur in the unaltered varieties of these igneous rocks.

Besides the porphyrites just described there is a more quartzose variety, found in several places, not far from the main stock. It has reached a somewhat higher degree of crystallization and exhibits mineralogical characters peculiar to the diorite of the stock, which will be fully described in that connection. There are also dikes or veins of coarser grained rocks cutting the body of the stock and passing into more massive portions of the same, which will not be considered with the finer grained dike rocks.

As already remarked, the microscopical characters of the minerals constituting these porphyrites are very nearly the same in all of the varieties.

Feldspar.—All the feldspars, so far as can be determined optically, are species of the lime-soda feldspar series. All of the porphyritical individuals are idiomorphic and exhibit the characteristic polysynthetic twinning according to the albite and pericline laws. Many of them are also twinned according to the Carlsbad law. The forms of their sections are lath-shaped, rectangular, and tabular, the general form of the crystals being tabular parallel to the clinopinacoid. They possess a fine zonal structure with varying optical orientation. From their optical behavior they appear to range from labradorite to oligoclase, the former occurring in the more basic porphyrites, rich in hornblende or pyroxene, the latter predominating in the more acid varieties, rich in phenocrystic biotite. The feldspars contain few primary inclusions, which are in some instances glass, in others microscopic grains of the other minerals. They are much richer in secondary inclusions, largely gas cavities, or needles of secondary amphibole.

The lath-shaped feldspars of the groundmass are also lime-soda feldspars, but the specific character of the irregularly shaped feldspar grains is not recognizable; they crystallized with the quartz at the time of the final consolidation of the magma.

The feldspars are more distinctly idiomorphic than the hornblendes, and are occasionally inclosed in large hornblendes; more rarely small hornblendes are inclosed in the feldspars.

Hornblende.—The primary, phenocrystic hornblende is more or less idiomorphic, but not always; occasionally its outlines are extremely irregular. It usually has crystallographic boundaries in the prism zone, consisting of the fundamental prism, ∞P, and the clinopinacoid, $\infty P\bar{\infty}$, the terminal planes, when present, being $P\bar{\infty}$ or P. Twinning parallel to the orthopinacoid is frequently observed.

The color varies from brown to green, through various tones of reddish brown, greenish brown, and light brown, brownish green, and olive gray, sometimes with a tint of red, which approaches a violet gray. The olive gray to violet gray tones are characteristic of much of the hornblende of the porphyrites occurring in the dikes and intrusive sheets; it is the component color transmitted parallel to the positive optic axis, c, in many cases. The other components in the same hornblendes are olive brown, parallel to b, and light brown, parallel to a. The absorption is $c>b>a$. The color is not always distributed uniformly through the individual crystals. It sometimes occurs in irregular patches, the darker color being generally in the central part of the crystal. It is evident that this regular distribution is sometimes due to the original crystallization of the hornblende, and at others has been occasioned by secondary influences, which tend to bleach out the color. A zonal distribution of the color is seldom observed.

The hornblendes throughout the series of porphyrites just described have very nearly the same tones of color in different sections, but as the basic end of the series is approached the colors grow slightly darker and the brown tones are stronger, approaching chestnut brown.

There are no characteristic inclusions. Iron oxide is frequently inclosed in the hornblende, and less often feldspar and apatite. When it is associated with porphyritical biotite the latter is often inclosed by the hornblende, and appears to be an older crystallization. In some cases the hornblende bears numerous patches of biotite, indicating that they have crystallized together. Where the hornblende is partly altered it sometimes contains biotite in shreds and irregular aggregates that are undoubtedly secondary.

The hornblendes of the dike rocks exhibit various degrees of alteration and decomposition, from those that are entirely fresh to those completely altered. The change is usually into chlorite, accompanied by epidote in irregular grains, which occasionally possesses a strong pleochroism, from colorless to yellow and deep garnet red; calcite and quartz are also developed. In some instances the compact hornblende is altered to light green "reedy" amphibole, usually accompanied by chloritization.

In the fine grained porphyrites the outlines of the phenocrystic hornblendes are sharply defined, as though the act of their crystallization had received a sudden check, but in the coarser grained porphyrites their outlines are often very irregular. Here the hornblende crystals have grown against feldspars and other minerals, according to circumstances, and are only partially idiomorphic.

In the variety described under (*g*), from a contact facies of the stock rock, the crystallization of the brown hornblende has varied greatly with different individual crystals within the area of one thin section of the rock. With some of the porphyritical hornblendes it has ceased suddenly, leaving them sharply outlined by crystal faces. With others it has carried the hornblende substance against crystals of feldspar and produced a rough surface. The margin of others is crowded with comparatively large grains of magnetite and is also rough. Some of the hornblendes have an irregular zone of magnetite and small feldspars, outside of which the hornblende substance is free from inclusions, but of very irregular form. In a few cases the crystallization of the brown hornblende has extended into the period of the final consolidation of the groundmass, and the resulting hornblende individual incloses within its extremely irregular outline the various constituent minerals of the groundmass. The color of these hornblendes is greenish brown and reddish brown, sometimes in irregular alternating zones, generally with the reddish brown color at the margin of the crystal. One large, ill-shaped individual, of very pure substance, free from cleavage cracks, has an irregular outline made up of small crystal faces, with some projecting forms like attached crystals of the same substance. The margin is a redder brown than the central part of the individual. Besides the primary brown and the greenish brown hornblende, there is a great amount of secondary green, reedy amphibole, resulting from the alteration of the pyroxene. It not only occupies the spaces of the original pyroxenes, but fills the groundmass of the rock with small needles. The primary brown hornblendes exhibit no signs of secondary alteration.

Biotite.—The porphyritical biotite occurs in six-sided plates and thicker crystals, occasionally twinned parallel to the basal plane. It is dark reddish brown, with characteristically strong absorption. Optically it appears uniaxial. Its substance is quite pure, with occasional inclusions of apatite and zircon; magnetite grains are scarce. In some instances it is partially bleached, and the light colored spots often contain bundles of rutile needles lying at right angles and also parallel to the edges of the basal plates. In the highly decomposed porphyrites it is completely altered to chlorite and epidote, sometimes with calcite and quartz.

The biotite of final consolidation, which occurs as a component of the groundmass and does not belong to the same period of crystallization as the porphyritical biotite, has the same optical characters, and can be distinguished only by its mode of occurrence.

Pyroxene.—The primary phenocrystic pyroxenes of the few pyroxenic dike rocks embraced in this grouping are recognizable only by their form, as they have all been uralitized.

Iron oxide.—In the absence of direct chemical tests and of characteristic crystal forms the exact nature of the iron oxide occurring in these porphyrites can not be determined. The chemical analyses of the rocks shows the presence of a variable percentage of titanic acid.

Apatite.—This mineral is more abundant in the porphyrites rich in phenocrystic biotite than in those free from it. It is colorless in most cases, but in the rock described under (*a*) it occurs in comparatively large gray crystals with slight pleochroism.

Zircon.—Zircon occurs in very small doubly terminated prisms. It is closely associated with the phenocrystic biotite, and is more abundant in the more siliceous porphyrites.

Secondary pyroxene.—The porphyrites in the metamorphosed sandstones are in some instances perfectly white. The feldspars are fresh and brilliant, as are also the small crystals of biotite scattered through the rock. In thin sections they are found to resemble the other porphyrites in general structure; their feldspars are very fresh, and bear numerous glass inclusions. The biotites are unaltered, but what from their crystal forms were evidently once hornblendes are now colorless augite. The hornblendes were originally very abundant, and the porphyrite belonged to the variety rich in hornblende, with a small amount of biotite and with no primary pyroxene. There are no porphyritical individuals exhibiting the crystal form of pyroxene. The augite substance which now replaces hornblende is sometimes compact, and exhibits cleavage characteristic of pyroxene. Cross sections in such cases have the crystal form of hornblende, bounded by the prism faces, making an angle of about 124°, together with the clinopinacoid, and exhibit a perfect prismatic cleavage of about 90° corresponding to the prismatic cleavage of augite, so oriented that the plane of symmetry in the augite coincides with that in the original hornblende. There is also a less

perfect pinacoidal cleavage. The substance of the augite is almost colorless, with numerous gas cavities in some instances. It is highly refracting and highly doubly refracting, and possesses a high extinction angle.

More frequently the augite is not compact, but is made up of small individuals with more or less parallel orientation; these individuals are not acicular but rather shortened prisms having an irregular form. The same augite substance occurs in irregularly shaped grains and patches through the groundmass in some cases.

Within the compact fresh feldspar a few small crystals of brown hornblende still remain unaltered. In some occurrences the hornblende phenocrysts are but partially changed to augite, which is scattered in microscopical grains and patches through the groundmass. These grains are sometimes crowded around an aggregation of colorless augite. In one instance the augite is confined to the space originally occupied by the hornblende. The specimens of porphyrite exhibiting this form of pseudomorphism are mostly from near the contact with the sedimentary strata and in the regions of contact metamorphism; one, however, is from a narrow dike of whitened porphyrite on the southeast spur, at a place where the strata are not so greatly metamorphosed.

The occurrence of secondary augite after primary hornblende is uncommon, the writer not having noticed any mention of it by others; it appears to correspond crystallographically to that of secondary hornblende after primary augite, though the two processes of alteration are reversed, and the causes producing them are undoubtedly different. What the causes may have been in this particular instance is not evident.

II. THE STOCK ROCKS AND APOPHYSES.

The diorite forming the body of the main stock, which is 1,500 feet across its widest exposure, presents a crystalline mass of variable grain. A great part of it is coarsely crystalline, and is composed of clusters of feldspars and ferromagnesian silicates that range from 5 millimeters to 2 millimeters in diameter, and smaller. The coarsest grain is shown in Fig. 1, Pl. XLVIII, photographed natural size from No. 201. The apparent grain of the rock is larger than it actually is, for the constituent minerals are not intermingled uniformly but irregularly, so that from two to a dozen crystals of feldspar are clustered together, and two or more of the dark colored minerals; this irregularity, however, recurs so regularly through the mass that the general effect is that of uniformity. The true size of the grain of these forms of the diorite, judged from the size of the feldspars, is from 2 millimeters to 1 millimeter. A medium grained form is shown in Fig. 2, Pl. XLVIII, natural size, No. 197. It constitutes a large portion of the diorite mass. The grain of the rock sinks to fine grained, and to microcrystalline in some instances. The variation in the grain of the rock is in some places gradual, in others rapid. As the rock becomes finer grained

it grows darker colored; the finest grained portions are dark gray. In numerous instances the gradual transition of this dark colored, fine grained form was traced through increasing size of grain to light colored, coarse grained diorite, and in the immediate vicinity of such transitions the two extreme forms are also found in juxtaposition, with a sharp line of demarcation between them, or the dark, fine grained form is cut by narrow dikes or veins of the coarse grained form. Along the contact there are in places many fragments of different forms of the diorite, dark and light, fine grained and coarse, which appear to have been broken from older portions of solidified diorite by later magmas, which also became diorite.

The mineral composition of the diorite is not uniform throughout the body of the stock, which may be easily recognized in the field. Portions of it are richer in the ferromagnesian silicates than the average, in which the proportions of the dark colored minerals to the light colored is about one to one. In places the light colored minerals preponderate. Parts of the body are noticeably richer in mica than the main mass, which appears, macroscopically, to be composed of lime-soda-feldspar, hornblende and biotite; the lighter colored varieties exhibit quartz, and the finest grained forms show only small porphyritical feldspars and pyroxenes. In general, there is an absence of porphyritic structure, the whole effect being evenly granular.

The component minerals of the diorites are hypersthene, augite, hornblende, biotite, lime-soda feldspar, orthoclase, and quartz. They are not all present in each variety of the diorite, however, for these varieties range from rocks with pyroxene and biotite to others with hornblende and biotite and still others with biotite alone as the ferromagnesian mineral. This range of mineral variation is shown in Table II, in which (*a*), (*b*), etc., represent different mineralogical modifications of the rocks.

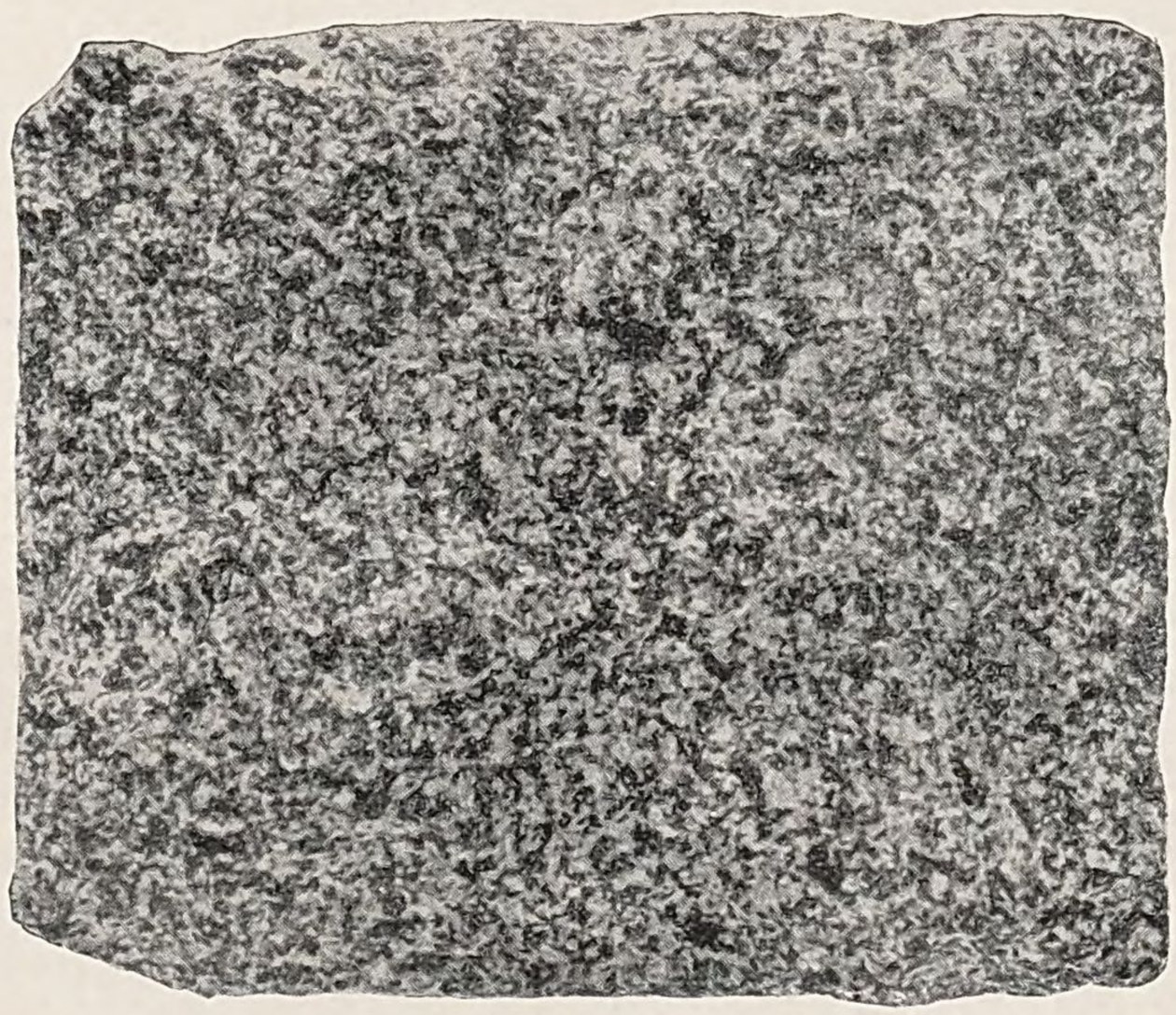
TABLE II.—*Mineral variation of the diorites and their facies at Electric Peak.*

	Pyroxene.	Hornblende.	Biotite.	Labradorite.	Oligoclase.	Orthoclase..	Quartz.
(*a*)	much	.....	little	much	some	.....	little
(*b*)	much	much	some	much	some	.....	little
(*c*)	little	much	much	some	some	little	some
(*d*)	.....	much	much	some	some	little	much
(*e*)	.....	some	much	little	much	little	much
(*f*)	.....	little	much	.....	much	little	much
(*g*)	.....	.....	much	.....	much	some	much

The main body of the diorite is cut by dikes or veins of equally coarse grained, lighter colored diorite, which sometimes approaches granite in character and in one instance is a fine-grained granite (Fig. 1, Pl. XLIX). In places the diorite is traversed by small seams of feldspathic material, which often pass into larger seams with more hornblende and biotite, and finally into veins having the composition and structure of quartzose diorite.



1



2

FIG. 1. DIORITE (COARSE GRAIN). FIG. 2. DIORITE (MEDIUM GRAIN).

Such narrow seams of feldspathic material appear to be the extremities of the larger cracks in the earlier solidified magmas into which the fluid portion of the subsequently intruded magma or magmas was forced; that is, they are distinctly eruptive in their origin, and not of a secondary nature. That portion of the magma which is the last to crystallize, namely, the feldspathic, furnishes the material that penetrates the extremely narrow cracks at the ends of the crevices, and the material in the intermediate portion of the crevice between the extremities and broader parts partakes more and more of the composition and character of the intrudedr ock. The microstructure of such seams is not that of the rock from which they spring, for the liquid portion of the magma will be gradually separated from the crystals suspended in it through the greatly increased internal resistance between the particles of the fluid consequent on its flow through such narrow passages.

Some parts of the diorite bear numerous small masses of coarsely crystallized rock, usually consisting largely of hornblende. They exhibit a variety of structures and appear to be segregations of early crystallization.

As already mentioned, there are contact facies of the stock which exhibit characters that ally them to the porphyrites: Such forms grade into the coarse grained diorites and appear to be portions of the mass that have been cooled rapidly in consequence of their contact with the inclosing rocks. On either side of the central portion of the stock and on the east side of the south end of it, the contact form of the diorite does not differ greatly from the main mass; it is somewhat finer grained, but not much. This indicates that the magma out of which this part of the diorite was formed was not chilled to any great extent by the surrounding rocks, and the inference is that the surrounding rocks were heated when this part of the magma came in contact with them. The occurrence of contact varieties of the rocks that range from fine grained prophyritic forms to coarse grained ones proves that the temperature of the rocks with which they came in contact varied greatly. Some were comparatively cold, others highly heated. If a series of eruptions followed one another closely enough to prevent the heat of one eruption from being entirely dissipated before the next one followed it, the surrounding rocks would be kept heated for a long period, and the last eruption of a series with regular intervals would pass through a hotter conduit than the earlier eruptions had passed through.

In describing the microscopical character of the stock rocks it will be convenient to separate them into three subgroups, according to some phases of their mineralogical composition indicated in Table II, as follows:

II (*a*) Varieties in which the amount of the dark colored minerals approximately equals that of the light colored minerals.

II (*b*) Varieties in which the amount of the light colored minerals exceeds that the dark colored minerals, and in which the quartz is not excessive.

II (*c*) Like II (*b*) but with much quartz.

By dark colored minerals are meant the ferromagnesian minerals and by light colored minerals are meant the feldspars and quartz.

This grouping brings together varieties with structures similar in some respects, though not necessarily of the same degree of crystallization; that is, size of grain. It also brings together rocks of approximately the same chemical composition; but the groups will be found to grade into one another chemically, mineralogically, and structurally, and do not represent any natural divisions of the rocks in the field, except in a general way. It brings together rocks which have different constituent minerals, the differences being among the species of the ferromagnesian silicates.

II (*a*) *Varieties in which the amount of the dark colored minerals approximately equals that of the light colored minerals.*—This group includes most of the main body of the stock rocks and is the most basic of the three groups. It embraces a closely allied series of varieties which vary structurally, mineralogically, and chemically within certain limits.

The specimens on which the microscopical study of this group has been based number thirty-two. They fall into a series of twenty-seven different degrees of coarseness of grain, of which it can only be said that each degree from fine to coarse is coarser than the preceding one. There has been no attempt made to establish a scale of uniform degrees.

Tables have been prepared to express as concisely as possible the various mineralogical, structural, and chemical features of the rock varieties under discussion. They will appear on a subsequent page and will be referred to frequently.

At the coarse grained end of the series, Table VIII, column II (*a*), p. 625, are the diorites which occur in the most massive exposures on the northeast spur and have reached the highest development of crystallization. Their structure is hypidiomorphic granular; that is to say, the component minerals have their proper crystallographic form to some ex. tent, but a large part of them have irregular shapes, occasioned by the interference of adjacent crystals during their crystallization.

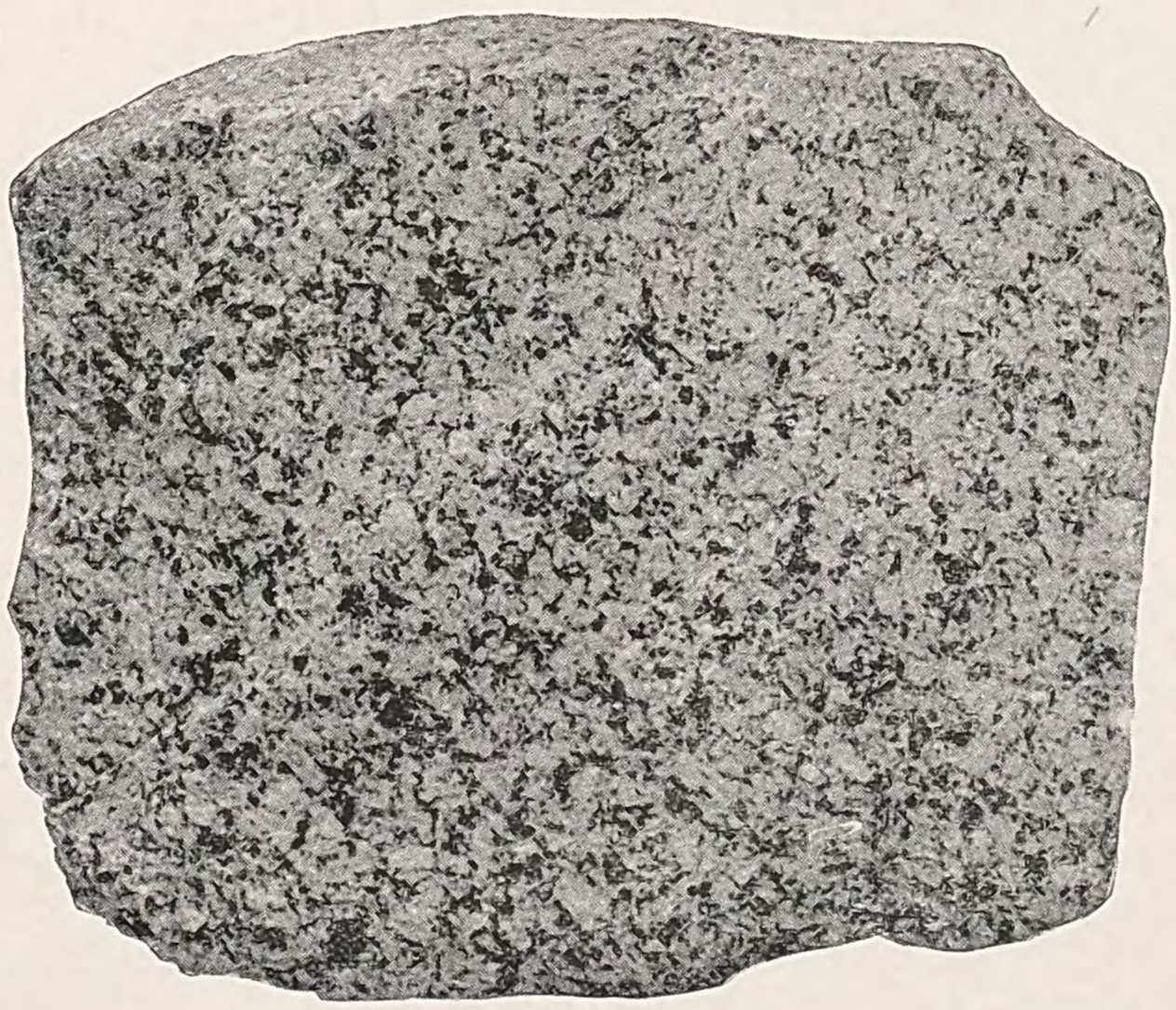
The component minerals are lime-soda feldspars, hornblende, augite, hypersthene, biotite, and quartz, with numerous grains of iron ore, which appears to be magnetite.

The feldspars are more nearly idiomorphic than the other constituents, but are not strictly so. They are mostly rectangular to lath-shaped. Their outlines are not sharp, crystallographic boundaries, but are more or less irregular ones, controlled by the growing together of neighboring feldspars. Their outlines are also affected in most instances by the juxtaposition of the other constituents of the rock.

The quartz forms irregular cementing grains, wholly allotriomorphic, and is evenly scattered through the rock in small amount.



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FIG. 1. GRANITE (FINE GRAIN).

FIG. 2. QUARTZ-MICA-DIORITE PORPHYRITE.

The hornblende, pyroxene, and biotite exhibit no crystal boundaries, with some exceptions, and penetrate one another in the most intricate manner.

The iron ore, from its crystal form, appears to be magnetite. It is irregularly scattered through the ferromagnesian silicates and is occasionly observed in the feldspars and quartz.

Apatite occurs in short, stout crystals, not very well formed, and colorless.

Zircon is rare.

The diorites representing the seven highest grades of crystallization in Table VIII, column II (*a*), correspond in structure to the description just given. They vary, however, in the relative abundance of hornblende, pyroxene, biotite, and quartz, as is indicated in the Table V. In the coarsest form the feldspars average from $2{\cdot}5^{mm}$ to 1^{mm} long, and the quartz grains about $0{\cdot}25^{mm}$ in diameter. In the seventh degree from the coarsest end, the feldspars average from $1{\cdot}25^{mm}$ to $0{\cdot}5^{mm}$ and the quartz grains about $0{\cdot}12^{mm}$.

As the grain of the rocks becomes smaller there is a greater development of idiomorphic forms, especially of the hornblende and biotite. Since all the other minerals are generally idiomorphic with respect to quartz, that is, are bounded by their proper crystal planes when adjoining quartz, the number of idiomorphic individuals of hornblende and biotite increase with the amount of quartz in the rocks.

Without any apparent interruption in the gradual variations in structure accompanying the diminution in the size of the grain, the structure of the thirty-third degree differs from that of the forty-fifth in that the number of partially idiomorphic individuals is very much greater. The feldspars are partly idiomorphic, partly allotriomorphic, some being rectangular, others broader and irregular in form like the quartz. Hornblende and biotite frequently exhibit their crystal form. Pyroxene is a prominent constituent, but is surrounded more or less by idiomorphic hornblende. The average length of the feldspars is $0{\cdot}46^{mm}$.

At grade 26 the grain is reduced to about half of that at 33, and averages about $0{\cdot}23^{mm}$, but there is more inequality between the feldspars, a porphyritic structure becoming more pronounced. Macroscopically, however, this variety of the rock has a uniformly granular habit.

The variety representing the twenty-third grade is composed of a mass of lath-shaped or rectangular feldspars and more irregular individuals of feldspar with some quartz. These average $0{\cdot}17^{mm}$ in length and carry many larger crystals of feldspar, besides much hornblende, pyroxene, and biotite, in very nearly equal proportions.

The next grade, 22, is considerably finer grained and has a somewhat different structure. It is still more porphyritic, the larger crystals of feldspar grading down into smaller ones, until they reach a diameter of about $0{\cdot}08^{mm}$. The smaller grains of feldspar are mingled with those

of quartz, and in the finer grained forms of this variety of the stock-rock give the groundmass its peculiar mottled appearance. The variety representing grade 22 bears much pyroxene and considerable mica, with less hornblende; magnetite is abundant in small grains or crystals.

Grade 14 is represented by a much finer grained form of rock with marked porphyritic structure. The groundmass is a holocrystalline aggregation of grains of feldspar and quartz, whose outline is poorly defined; it is filled with microscopic pyroxenes and magnetite grains. The phenocrysts are lime-soda feldspar, hypersthene, augite, with some irregular patches of biotite. There is no hornblende. The porphyritical pyroxenes range from $0{\cdot}5^{mm}$ to $0{\cdot}25^{mm}$ approximately.

The varieties representing the five grades, from 17 to 13 inclusive, have very much the same structure and composition, and might be classed as holocrystalline *pyroxene-porphyrites*. They belong to the main body of the stock rocks and form with them one geological body, the fine grained variety grading by imperceptible transitions into the coarse grained. They also have nearly the same chemical composition.

This group of rocks, therefore, presents a continuous series of varieties, that range from fine grained hypersthene-porphyrite with small phenocrysts to coarse grained hornblende-mica-diorite with a variable percentage of pyroxene.

The essential character of the minerals constituting the different varieties under consideration are much the same throughout the series, and since the variations in their microscopical character are intimately connected with the general structure of the rock in each case, and have an important bearing on the question of the development of crystallization in the rock, it seems advisable to describe the microscopical characters of the various minerals with reference to these variations. For this reason the detail description will begin with the minerals as they occur in the finest grained forms, although these forms are not the most characteristic of the main body of the stock. Such a method of treatment is admissible when it is considered that the different varieties included in this grouping have in some instances been collected from one continuous rock mass within short distances of one another, and were intended to illustrate the actual transition of the fine grained forms into the coarse grained. Thus, specimens Nos. 172, 173, 174, 175, 183, and 191, were collected from a continuous exposure of massive rock which exhibited a gradual transition of grain. They occurred about 1 foot apart in the order given, the extremes being 5 feet apart. The grain of the rock changes rapidly from No. 175 to No. 183. Specimen No. 170 is from the same body of rock as Nos. 172, 173, etc. Specimens Nos. 181, 182, 185, 188, and 193 are also from one continuous mass of rock exhibiting a gradual change of grain. They all occurred along a line not more than 4 feet long. The mass from which they were taken was continuous with that from which No. 171 was collected, and was within a few feet of it. These two series were collected within

a hundred yards of one another and appeared to be portions of the same mass. They range from the thirty-fifth to the thirteenth grade of crystallization (Table VIII).

Microscopical characters of the feldspars.—In the finest grained form of pyroxene-porphyrite, No. 170, the porphyritical feldspars that lie scattered through the holocrystalline groundmass are sharply idiomorphic. They are lath-shaped and rectangular, some having less regular outlines. They all exhibit polysynthetic twinning and high angles of extinction which indicate that many individuals belong to labradorite. They vary greatly in regard to inclusions: many are nearly free from all kinds of inclusions, others are so filled with them that the feldspar substance is subordinate to that of the foreign minerals. These are mostly pyroxene in rounded grains and prisms, and magnetite, which are also abundant in the groundmass. In some instances the section of a feldspar appears darker than the surrounding groundmass, for the pyroxene and magnetite grains are smaller and more abundant in the former. Some of these impure feldspars exhibit low extinction angles and interference colors, but others appear to be of the same species as the feldspars free from inclusions. Zonal structure is well marked optically, and occasionally controls the arrangement of the inclusions. Some feldspars bear colorless glass inclusions, but they are not very numerous.

Where the feldspar and pyroxene phenocrysts are clustered together, the latter are surrounded by the former, and the crystal form of the pyroxene is interfered with by the feldspars, proving that the pyroxenes began to crystallize before the feldspars, but did not finish before the feldspars commenced. These surrounding feldspars have variable amounts of inclusions.

The feldspars in the next variety, No. 171, have much the same characters as those just described. The inclusions in the different feldspars vary from almost none to great numbers evenly distributed through the crystal. In some they are confined to the margin, in others to the center of the individual. Some feldspars contain swarms of minute dots and short needles or rods apparently opaque. The needles are arranged in a number of sets of parallel lines, which do not appear to bear any fixed relation to the axes of the crystals, for they pass through twin lamellæ without change of direction. They are sometimes more abundant in one lamella than another and usually form irregularly shaped clouds, which exhibit no connection with cracks or cleavage planes in the feldspars. They appear to be primary. These minute dots and needles occur with the other inclusions—magnetite grains, pyroxene, apatite, and glass.

In the next three grades of the rock specimens, Nos. 172, 173, and 174, the feldspars are like those described, but their crystallographic outline is less sharply defined. In grade 22, No. 175, the porphyritical feldspars have a narrow marginal zone of purer feldspar substance. It has much fewer inclusions, sometimes being free from them.

It exhibits the same twinning as the inner feldspar, but has a lower angle of extinction, which indicates that the outer zone is composed of a more alkaline lime-soda feldspar than the central portion. The inner feldspar has a sharp idiomorphic form, while the outer zone is allotriomorphic, having crystallized against other individuals in the groundmass. The zones around the large and small feldspars are of about the same width and are apparently synchronous. In the groundmass there are small, rectangular, unstriated feldspars scattered through larger individuals of quartz. There are only a few grains of pyroxene in the groundmass; magnetite is quite abundant in grains which are smaller than in the finer grained varieties of the rock.

In the same rock, 1 foot from the last specimen, the grain is considerably coarser and is grade 29, No. 183. Here the feldspars are larger, the central portion has the same kinds of inclusions as the feldspars just described, with the addition of a little hornblende in rounded grains and biotite in minute plates. The marginal zones are broader and of very pure substance. The feldspar and quartz of the groundmass is in larger grains. At the distance of another foot the rock is grade 33, and the character of the feldspars is about the same as in those forms of the rock just described.

In the varieties embraced in the series Nos. 181, 183, 185, 188, and 193 the phenocrystic feldspars have the same characters and inclusions as those just mentioned. The central core carries more or less inclusions of magnetite, pyroxene, biotite, hornblende, and apatite; the outer zone is of pure feldspar substance. As the coarser grained form, No. 193, grade 35, is approached the number of these kinds of inclusions in the feldspars diminishes and their size increases. The swarms of black dots and needles occur in various feldspar individuals throughout these grades. The feldspars in the other forms of the rock represented in the table between grades 13 and 35 have the same characteristics as those in the series described. It is observed that the number of individulized inclusions decreases as the rock is coarser and that the swarms of dots and needles increase. In the coarser grained forms biotite and hornblende occur with the pyroxene and magnetite as inclusions in the larger feldspars. In many of the feldspars there are colorless rectangular inclusions, with a black dot near one end, which are oriented parallel to the vertical axis of the crystals. In most cases they behave like isotropic substances, but occasionally appear to be doubly refracting. The black dots do not appear to be spherical and the nature of the inclusions is doubtful; they suggest glass inclusions, but are indeterminable.

In the still coarser grained forms the feldspars are larger, the presence of a central core with a margin of more alkaline feldspar is still recognizable in most individuals though not in all. Inclusions of the ferromagnesian silicates are less abundant, but those of opaque dots and needles are more so; in some cases giving a brown tint to the feld-

spar. They are confined, almost exclusively, to the inner feldspar, which sometimes exhibits fine zonal structure. The twin lamellæ are much broader than in the small porphyritical feldspars of the fine grained forms. In some individuals there are many thin lamellæ twinned according to the albite and pericline laws. None of the outlines are idiomorphic. As the grain of the groundmass becomes very coarse it is evident that among the irregular grains of feldspar, most of which are striated, there are some of orthoclase. These never exhibit an approach to idiomorphism and share with the quartz a completely allotriomorphic habit. These two minerals were undoubtedly the last to crystallize out of the magma.

The large feldspars of the coarsest grained form of the rocks are about three times as large as the porphyritical feldspars in grade 13. In the coarse grained forms they have the characteristic inclusions and twinning of labradorite, as it occurs in many gabbros and norites. In most of the sections the feldspars are extremely fresh and unaltered, in a few they are partly clouded in the central portion.

The *quartz* occurs in allotriomorphic grains with the most irregular outline; it fills the interspaces between the other minerals. In the finer grained varieties of the rock its substance is extremely pure, and free from characteristic inclusions. There are almost no gas inclusions; minute crystals of apatite with occasional grains of other minerals are often inclosed by it. In the coarser grained varieties the quartz carries more gas inclusions, often in dihexahedral shapes; fluid inclusions are less numerous; the relative amount of fluid in the cavities varies considerably; in rare instance the bubble is in motion. The abundance and size of the gas cavities increases with the coarseness of the grain of the rock.

The *pyroxenes* in these rocks are hypersthene and augite, the relative amounts of which are variable. The hypersthene is distinctly pleochroic in thin sections; the colors are green || c, yellow || a, and light red || b. Very rarely there is zonal difference in the color of the hypersthene; this is noticed on strongly colored individuals. The form of the phenocrysts in the finest grained rocks is in part idiomorphic, some of the crystals being sharply defined; the outline of others is rough in the prism zone, and fringed at the terminations by the projection of microscopic crystals of pyroxene. The greater number are quite irregularly shaped, and exhibit no crystal outlines. In the well formed crystals the pinacoids are large and the prism faces small. Cleavage is not well developed, and is often absent from longitudinal sections; a prismatic cleavage is most always observed in cross sections. Occasionally there is a cleavage or parting parallel to the brachypinacoid. The augite is light green in thin sections and is not pleochroic. Its forms are similar to those of hypersthene, but the cleavage is more pronounced and is always present in longitudinal sections. It is occasionally twinned parallel to the orthopinacoid. It is distinguished from hypersthene by

its optical characters. The two species are often easily confused when the hypersthene sections are not distinctly pleochroic. Their general habit, their form, substance and inclusions, and their behavior toward the other minerals associated with them, are so much alike that they may be described together as the pyroxenes.

In the few instances where decomposition has affected the rocks under investigation the hypersthene has yielded before the augite. Most of the rocks, however, are remarkably fresh and exhibit no signs of decomposition. The substance of both the phenocrystic hypersthene and augite is mostly very pure and free from characteristic inclusions. Some of the large pyroxenes bear numerous irregular colorless inclusions, with no bubbles, and of an indeterminable nature, besides grains of magnetite. In the fine grained varieties of the rock the microscopic pyroxenes bear numerous grains of magnetite and rounded grains of the colorless indeterminable mineral. These microscopic pyroxenes, which fill the groundmass of the varieties of the rock, are mostly rounded, but are also idiomorphic. They appear to be in part hypersthene and in part augite. They have attached themselves with parallel orientation to some of the porphyritical pyroxenes, producing very irregular outlines. In other cases, the growth of the large individuals has continued into the period of crystallization of the microscopic ones, for they have added to their purer substance a margin of pyroxene material filled with the same minute inclusions that occur in the microscopic individuals. This is true of both the hypersthene and augite.

Where individuals of the two species have grown in conjunction the hypersthene is evidently the older, being inclosed by augite. The two are sometimes intergrown, indicating that their crystallization was in large part synchronous. The character of the intergrowths of these two mineral species is especially important because of its bearing on the intercrystallization of other minerals in these rocks. The hypersthene generally occupies the central place, and is often entirely surrounded by the augite, but quite as frequently the augite only partially surrounds the hypersthene, and occasionally the two penetrate one another irregularly and intimately. In the cases where the hypersthene is surrounded by augite, the hypersthene possesses no crystallographic form or outline, but is irregularly rounded or rough and jagged (Pl. L, Fig. 1). The augite material is in direct contact with the irregular surface of the hypersthene, and forms a single augite individual, oriented parallel to the inclosed hypersthene. There is often no physical line of demarcation between the two substances, except that produced by a change of color when present, and by the different optical effects between crossed nicols. When the section of the two minerals exhibits nearly the same color for both, the presence of an intergrowth may easily be overlooked in ordinary light. The cleavage fractures and cracks often traverse the two minerals without noticeable change of direction, and behave as though the compound individual were a simple

one. In places where the plane of contact between the two minerals is inclined to the axis of the microscope (line of vision) the colors of the two blend into one another, as do also their interference colors between crossed nicols.

In one instance a group of pyroxenes and feldspars have crystallized in conjunction. The hypersthene and augite exhibit almost the same color, the pleochroism of the hypersthene being almost imperceptible. In the illustrations on Pls. L and LI, the colors given to the various minerals are in a measure conventional. They are those characteristic of the minerals under certain conditions, and have been used in this way in order to avoid a multiplicity of colors or tones, or the necessity of reproducing the colors exhibited in polarized light. In the intergrowth just mentioned a large, irregularly outlined pyroxene appears in ordinary light to be a homogeneous individual, traversed by irregular cracks and imperfect cleavage planes. Between crossed nicols it resolves itself into an intergrowth of hypersthene and augite, whose substances interlock irregularly, as shown in the illustration. (Pl. L, Fig. 2.) There is nothing in the section, viewed in ordinary light, to indicate where the hypersthene substance ends and the augite begins. They have evidently crystallized at the same time and have interlocked crystals.

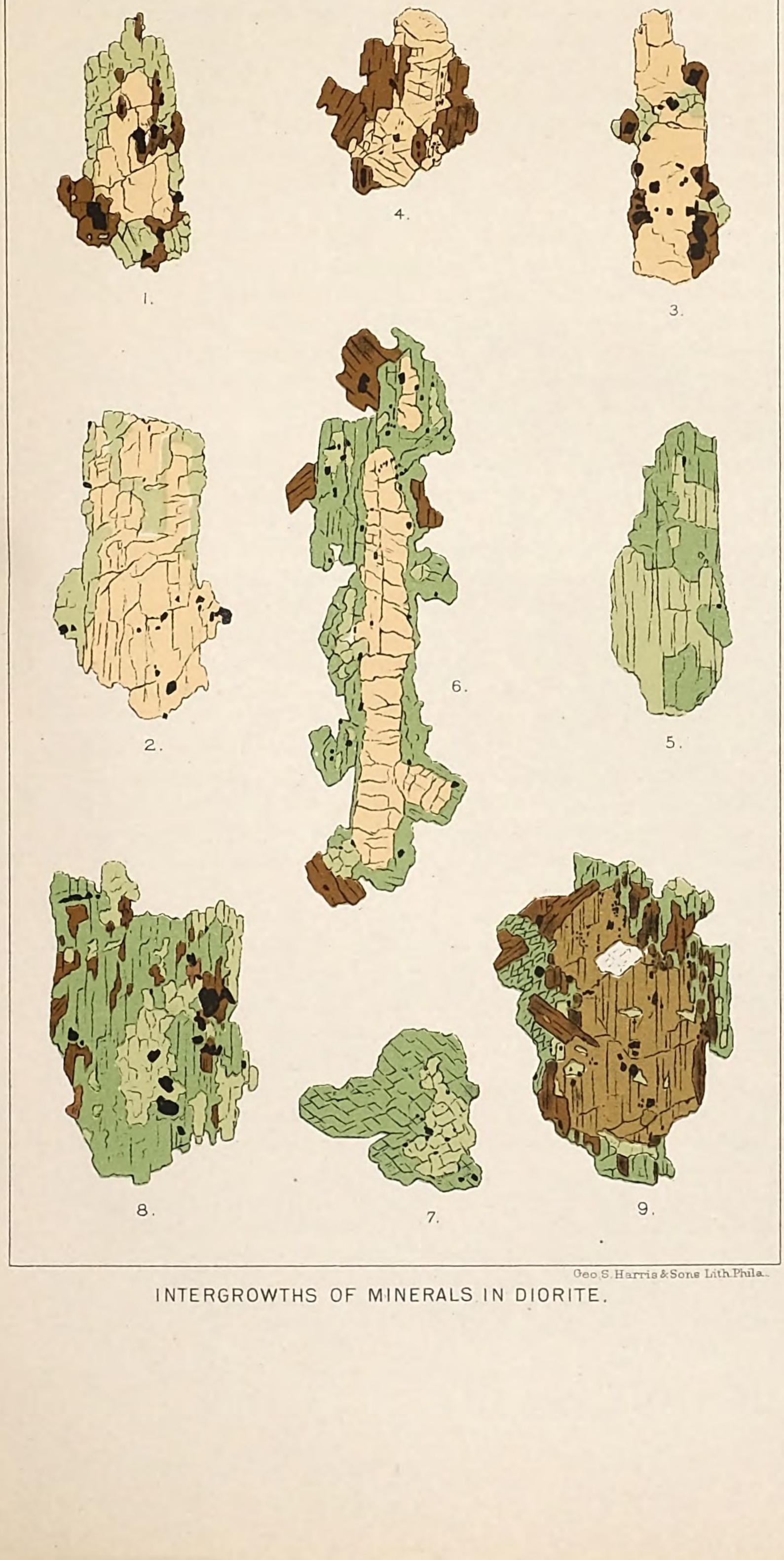
The pyroxenes inclose comparatively large grains and crystals of magnetite, with which biotite is intimately associated. In the coarser grained varieties of the rocks the pyroxenes exhibit the same optical characters as those in the fine grained, which indicates that their chemical composition is nearly constant. Their form becomes more and more irregular and their size larger, but they are fewer in number and become less prominent as a constituent of the rock.

The *biotite* is in irregularly shaped patches, usually composed of one individual. In many cases it surrounds the magnetite completely, especially when lying in the groundmass. But where they are connected with the large pyroxenes the biotite often occurs on the side of the magnetite farthest from the center of the pyroxene and extends to the outside of the latter, as shown in the illustration (Pl. L, Figs. 1 and 3), indicating that it began to crystallize about the time the attached magnetite was being inclosed in the pyroxene, and continued after the pyroxene's growth ceased, as it grows larger toward the outside of the pyroxene crystal and is often found surrounding the latter. The surface of contact between the pyroxene and biotite is very irregular and indicates that they interfered with each other's growth. The crystallization of the biotite appears to antedate that of the microscopic pyroxenes of the groundmass, but not wholly, for the biotite occasionally incloses grains of pyroxene. Its growth was interfered with by the feldspars of the groundmass, which it sometimes incloses in rounded grains. Biotite and pyroxene occur intergrown in the same irregular manner as that observed between hypersthene and augite, but the crystallographic orientation is not so uniform. The biotite is the outside min-

eral. The irregularity of the boundary between the two minerals is shown in the accompanying illustration (Pl. L, Fig. 4) from No. 174. As the rock becomes coarser grained the biotite is better developed, that is, it is in larger patches and is more abundant. There is only a little biotite in the finest grained variety of the rock, grade 13. The character of the biotite is constant throughout this group of rock varieties. It is dark brown, with strong absorption and an almost uniaxial optical character. Its form is allotriomorphic and very irregular; the size of the individuals increases with the grain of the rock. It has no characteristic inclusions.

Hornblende appears as an essential constituent of the rock as it becomes coarser grained. At grade 22, No. 175, the hypersthene and augite individuals are surrounded more or less completely by compact brownish green hornblende, which also occurs to some extent in independent individuals. In other and coarser grained varieties of the rock, where it maintains the same relation to the pyroxenes, it sometimes exhibits sharply defined, idiomorphic forms. Cross sections are bounded by the prism faces making an angle of 124°, and by the clinopinacoid as a small plane, with the orthopinacoid strongly developed. The characteristic prismatic cleavage is always present in cross sections, but does not always appear in longitudinal sections. Terminal planes are also observed in some instances. But the great majority of individuals are allotriomorphic, and have very irregular outlines of the same character as those of the pyroxenes in the finer grained varieties of the rock. They are in no case acicular or columnar, but are always compact. The pleochroism is brownish green parallel to c and b, and light brown parallel to a; $c > b > a$. There are no characteristic inclusions, but magnetite and biotite are often included in great amount.

The hornblende has crystallized around the augite and hypersthene in the same manner as that in which the augite surrounds the hypersthene. It is observed immediately surrounding either of the pyroxenes singly, or both together. In most cases the growths are parallelly oriented, but the pyroxene is frequently inclosed by the hornblende in various orientations. The line of demarcation between the two is as indefinite and as irregular as that between the hypersthene and augite. The pyroxene is very irregularly bounded and the union of the hornblende and pyroxene substances is often so perfect that the color and optical characters alone distinguish the different individuals. In longitudinal sections the cleavage is frequently continuous through both minerals, but in cross sections and inclined sections the cleavage is no longer parallel. It also happens occasionally that the pyroxene possesses irregular fractures which do not penetrate the hornblende. There is no uniform relation between the position or amount of hornblende and those of the inclosed pyroxene. The hornblende may form a narrow or broad border around the pyroxene or may surround only a part of the pyroxene, or they may occur independently of each other; all these



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INTERGROWTHS OF MINERALS IN DIORITE.

different relations are observed in the same thin section. The irregularity is shown in the illustrations. Pl. L, Fig. 5, represents an intergrowth of augite and green hornblende, and Fig. 6 represents an irregular growth of green hornblende around hypersthene. The hornblende incloses some grains of augite and magnetite, and has four individuals of biotite attached to it. The primary nature of the hornblende is unquestionable; cross sections exhibiting the intergrowth are observed in great numbers and in all cases where the outline is bounded by crystal faces it exhibits the characteristic forms of hornblende, as in Pl. L, Fig. 7. The hornblende does not penetrate the pyroxene in acicular needles; the junction between them is often sharp-edged and well defined by the color. Where the plane of junction is inclined to the line of vision, the two minerals wedge out in the section and their colors appear to shade into each other.

The hornblende not only surrounds the pyroxene in the manner just described, but in many cases intermingles with it in parallel orientation, presenting an intergrowth of the two minerals which corresponds exactly to the intergrowth of hypersthene and augite already described. This is oftener observed in the coarser grained varieties of the rocks than in the finer grained, but occurs in the latter also. Such an intergrowth is represented in the illustration, Pl. L, Fig. 8, taken from the coarsest grained variety, No. 202. The outline between the hornblende and augite is distinct; the shapes of the augite within the hornblende are very irregular, but the augite on the outer edge has its crystal form and appears to have continued its growth after the hornblende had ceased. They have evidently crystallized contemporaneously. The relative amount of hornblende and pyroxene varies in the different modifications of the rock studied. In some the hornblende greatly preponderates over the pyroxene, which occurs scattered through the hornblende individuals. This relation is expressed approximately in Table V.

Biotite and magnetite occur in the same connection with the hornblende as with the pyroxene in the finer grained varieties. Magnetite is scattered through the hornblende very irregularly, being abundant in some cases and absent in others. Biotite is often intergrown with the hornblende and pyroxene groups, and also incloses them in many cases, and occurs in isolated individuals with irregular shapes. The greater part of its growth seems to have been later than that of the hornblende.

A dark brown variety of hornblende occurs in some of the rocks of this group. Its relations to the other minerals are of great interest in connection with the question regarding the magmas involved in this complicated series of eruptions. It is chestnut brown to greenish brown, and resembles in this respect most of the porphyritical hornblende in the andesites of Sepulchre Mountain. It occurs in irregularly shaped individuals intergrown with the other minerals in such a manner as to indicate their nearly contemporaneous growth. In many cases it is evident that it is distinctly different from the brownish green hornblende. This is brought out by such groups as that represented by Fig. 9, Pl. L.

As in the illustration, the dark brown hornblende generally forms the central body of the mineral group, but sometimes incloses small individuals of feldspars, augite, and hypersthene with magnetite. Biotite is included near the margin of the brown hornblende, but is more abundant in the green hornblende which surrounds the brown hornblende. It frequently occurs in this association and indicates that in these instances the crystallization of the biotite set in after that of the brown hornblende and before that of the green, though its crystallization in many cases appears to set in after that of the green hornblende.

There are instances where the distinction between the dark brown and the green hornblendes is not so definite and is not separated by the commencement of the crystallization of a third mineral. In these cases the form of the brown hornblende is exceedingly irregular; the boundary between the two is sometimes sharp edged, but often is indeterminable, and the two shade into each other. There is usually no approach to a zonal arrangement of the colors, and their distribution is as irregular as the outward form of the individual or as that of the intergrown minerals already described. The general absence of zonal structure in the hornblende and pyroxenes of this group of rocks is noteworthy and will be discussed subsequently. It appears to some extent in the distinctly porphyritic modifications of the rock. In the contact facies of the diorite, already described, No. 139, the idiomorphic form of the hornblende is accompanied by a zonal distribution of the color. The reddish brown color occurs at the center and also along the margin of brownish green hornblendes and appears to be the result of primary crystallization. In the same way the brown hornblende in the coarse grained diorites appears to belong to a phase of the hornblende crystallization distinct from that of the brownish green hornblende.

Magnetite occurs in well developed crystals and irregular grains, which contain more or less titanic oxide as shown by the chemical analyses. In the porphyritic varieties of the rock, magnetite appears in large porphyritical grains and in a multitude of minute grains in the groundmass, evidently the product of two generations. As the rock becomes coarser grained the individuals of magnetite are larger and fewer in number. In the coarsest grained varieties they are much fewer in number and appear to belong to one generation.

Apatite is not observed in the finest grained varieties of the rock, but is first noticed in the twenty-third grade, No. 176, where it occurs in microscopically minute crystals, sharply idiomorphic. As the grain of the rock increases they appear as larger and larger crystals, but fewer in number. Their size and amount are not perfectly regular throughout the different varieties of rock included in this group, so that there is no definite relation between the size of the apatite and the grain of the rock, but the variation in size and amount is very noticeable in a general way. They attain their largest development in No. 201, where they reach 0·45 ^{mm}. In this rock their form is irregular, with no crystal outlines.

Zircon is scarce. It is not noticed in the finest grained varieties of the rock. It first appears in very small crystals and in the coarser grained rocks it is in larger crystals. Thus both the zircon and apatite in this group of rocks appear to vary in size with the grain of the rock; that is to say, their crystallization was influenced by the conditions which controlled the degree of crystallization of the whole rock.

Recapitulation.—Some of the variations in the microscopical habit of the minerals composing this group of rocks may be briefly recapitulated as follows:

The idiomorphic feldspars and the zonal portion of the allotriomorphic ones increase in size with the grain of the rock. Their twin lamellæ become broader; the number of inclusions of ferromagnesian silicates and magnetite diminish, and the abundance of minute dots and needles increases with the grain of the rock. The feldspar, forming irregular grains in the groundmass of the porphyrites, crystallizes as a border around the idiomorphic individuals in the coarser grained varieties; is allotriomorphic and more alkaline. Orthoclase is recognizable in the coarsest grained varieties.

Quartz occurs only in allotriomorphic individuals, which are nearly contemporaneous with the orthoclase. The gas and fluid inclusions increase in number and in size with the size of the quartzes and the grain of the rock.

Hypersthene and augite occur in idiomorphic and allotriomorphic individuals in the porphyrite; are much more irregularly shaped in the coarser grained varieties of the rock and are in larger individuals.

Primary brownish green hornblende occurs in the same manner, and dark brown hornblende appears as an independent crystallization, but is not always present.

Biotite occurs almost wholly in allotriomorphic forms.

The ferromagnesian silicates occur isolated to some extent, but are generally intergrown in the most intimate manner. There is an apparent order in the time when they started to crystallize, but they have evidently grown synchronously to a large extent. This is more noticeable in the coarser grained varieties of the rock, where all of the minerals exhibit mutual interference with those near them in the order of crystallization. Where the extremes of this order are in conjunction the older mineral has its idiomorphic form.

Magnetite occurs in two generations in the porphyrites; the evidences of a second generation cease as the rock becomes coarse grained, and the size of the individuals increases and their number diminishes.

Apatite occurs in abundant minute idiomorphic crystals in the finer grained varieties, and is in much fewer, larger, poorly shaped individuals in the coarse grained varieties.

Zircon is more noticeable in the coarser grained rocks, and is in larger crystals.

INTERGROWTH OF HORNBLENDE AND PYROXENE IN GLASSY ROCKS.

It is important to emphasize the primary nature of the hornblende found intergrown with the augite and hypersthene in the diorite just described. Similar intergrowths are mentioned by Prof. Rosenbusch as of common occurrence in those diorites in which all of these minerals are developed.[1] Its resemblance to certain paramorphic changes of pyroxene to compact hornblende in other coarse grained rocks described by George H. Williams,[2] G. W. Hawes,[3] R. D. Irving, and C. R. Van Hise,[4] may in some minds cast a doubt on its primary nature in the rocks under investigation. It is to be remarked that Prof. Williams in his paper observes with regard to the cases described by the other investigators mentioned, "In neither of these instances, however, are the proofs of paramorphism adduced entirely convincing." In his own paper he rests his case on the very irregular boundary between the pyroxene and hornblende, on the fact that the hornblende penetrates the pyroxene in the form of "the most delicate possible tongues and shreds," extending "in every direction, though they seem to be most developed in the direction of its cleavage." And, further, on the apparent gradual transition of one mineral into the other optically.

With regard to the last observation it is self-evident that thin edged portions of minerals with similar indices of refraction, which wedge out against one another within the space of a rock section, appear to pass into one another by insensible gradations of color. This can be observed in the case of inclined contacts between hypersthene and feldspar in which case there is no suspicion of an actual transition of substance or intermediate stage of chemical character. There is no direct evidence brought forward in the paper cited to show by the crystal outline of the mineral that the original form was that of a pyroxene, as in the case of uralite. The whole argument seems to the writer to hang on the fact that the hornblende penetrates the pyroxene in tongues and shreds, in which respect it resembles the paramorphism of pyroxene to uralite. From the writer's acquaintance with instances of undoubtedly primary intergrowths of hornblende with other minerals, the last-mentioned argument for the paramorphism of compact hornblende from pyroxene does not seem to him to be sufficient. Because of the doubt which may have been cast upon the primary nature of certain intergrowths of hornblende and pyroxene it has seemed advisable to recall to those who have studied glassy volcanic rocks, and to present to those unfamiliar with them, some of the numerous instances of the nearly contemporaneous crystallization of hornblende and pyroxene, which are identical with those observed in the diorite at Electric Peak. Their occurrence in perfectly

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[1] Mikroskopische Physiographie der Massigen Gesteine. Stuttgart, 1887, p. 119–120.

[2] On the Paramorphosis of pyroxene to hornblende in rocks. Am. Jour. Sci., Oct., 1884, vol. 28, p. 259–268.

[3] Mineralogy and Lithology of New Hampshire, pp. 57–206; Pl. VII, fig. 1.

[4] Geology of Wisconsin, 1880; vol. 3, p. 170. Am. Jour. Sci., July, 1883; vol. 26, p. 29. Geology of Wisconsin, 1882; vol. 4, p. 662.

fresh, glassy, and often pumiceous surface lavas makes it evident that the two minerals have crystallized out of a molten magma at very nearly the same time, and are not the result of metamorphism subsequent to the consolidation of the rock.

In the glassy hornblende-pyroxene-andesites of Sepulchre Mountain there are instances of the conjoint growth of hypersthene, augite, and brown hornblende. The pyroxene and hornblende are occasionally grown together with an irregular line of demarcation between them. The hornblende partly surrounds the pyroxene and appears to be the younger mineral. In one instance a large individual of brown hornblende is surrounded by a border of augite crystals in nearly parallel orientation. The outline of the inclosed hornblende is irregular, but exhibits no evidence of resorption and bears no magnetite. The other hornblendes are idiomorphic.

In some of the other hornblende-pyroxene-andesites from this region red porphyritical hornblende is found to include pyroxene in irregularly shaped grains and in different orientations, showing that in these cases the hornblende crystallized after the pyroxene commenced to crystallize.

The most striking examples of these intergrowths that have come to the writer's notice and that furnish good subjects for illustration are found in pumiceous glassy andesites from different parts of North and Central America.

In a very glassy andesite from Santa Clara Canyon, New Mexico, described in a recent bulletin of the Survey,[1] there is a fine instance of the inclosure of hypersthene by dark brown hornblende, Fig. 4, Pl. LI. The substance of the hypersthene is very pure and resembles that of the idiomorphic hypersthenes scattered through the colorless glass. The form of the inclosed hypersthene is very irregular. The inclosing hornblende has crystallized directly upon the hypersthene and forms a border round it. The outline of the hornblende is only partly idiomorphic, as it has grown against other individuals of hornblende in different orientations. The inclosing hornblende is the same as the idiomorphic hornblende scattered through the glass, and contains a great number of crystals of magnetite.

In a glassy hornblende-andesite from the mouth of Silver Creek, Utah,[2] the dark brown porphyritical hornblendes inclose irregular grains of pyroxene. One individual is especially interesting, as it incloses both augite and hypersthene. The irregular shapes of the inclosed pyroxenes are shown in Fig. 5, Pl. LI. This is very similar to what is observed in the diorites at Electric Peak, except that the hornblende is dark brown instead of brownish green. Excellent examples of the same thing are found in an andesite from Skellig Ridge, Elk Head Mountains, Colorado.[3] The groundmass of this rock is filled with small pyroxenes and

[1] On a group of volcanic rocks from the Tewan Mountains, New Mexico, and on the occurrence of primary quartz in certain basalts. J. P. Iddings, Bull. U. S. Geol. Surv., No. 66, 1890.

[2] Collection of the Fortieth Parallel Survey, No. 319 (20645).

[3] Ibid., No. 323 (20487).

brown hornblendes, and the hornblende frequently incloses the pyroxene, as in Fig. 6, Pl. LI. In this instance the hornblende surrounds the augite.

In a glassy hornblende-pyroxene-andesite from Lassen Peak, California,[1] the intensely red hornblende occasionally surrounds the pyroxene. This is shown in cross section in Fig. 7, Pl. LI.

The same thing is observed in the pumiceous, glassy dacite from the same locality.[2] Irregularly shaped pyroxene forms the center of dark greenish brown hornblende, which is distinctly idiomorphic, and has the prism ∞P, and both pinacoids, $\infty \breve{P}\infty$, $\infty \bar{P}\infty$; this is shown in Fig. 8, Pl. LI. Another instance of the intergrowth of pyroxene and dark greenish brown hornblende from the same dacite is illustrated in Fig. 9, Pl. LI. The pyroxene in this case is hypersthene. The character of the intergrowth is exactly the same as of those in the diorite at Electric Peak. Such intergrowths are not rare occurrences in this glassy rock, and are not confined to the pyroxene and hornblende. Irregular individuals of olivine surrounded by the same kind of hornblende are frequently met with. Olivine surrounded by reddish brown hornblende also occurs in a hornblende-pyroxene-andesite from Mount Ranier, Washington.[3] The same association of accessory olivine and inclosing hornblende is found in a pumiceous glassy hornblende-pyroxene-andesite from Salvador, Central America.[4] Intergrowths of hornblende and pyroxene occur in these rocks also.

In this connection it may be well to call attention to an exceptional intergrowth that will illustrate how intimately minerals of altogether different composition and habit may crystallize. It is the mutual penetration of hypersthene and plagioclase which form a porphyritical group in a glassy hornblende-pyroxene-andesite from Mount Hood, Oregon.[5] The two minerals are perfectly fresh and so oriented that the striations of the plagioclase are parallel to the vertical crystallographic axis of the hypersthene (Fig. 10, Pl. LI). The feldspar carries a great amount of fine glass inclusions, in which there is occasionally a minute crystal of magnetite. The hypersthene carries a few irregularly shaped inclusions, which may be glass, but do not contain spherical gas bubbles. It incloses numerous grains of magnetite and colorless prisms of apatite, which are also scattered through the feldspar. The difference between the association of the inclusions in each mineral is very noticeable. The minerals evidently crystallized out of the same glassy magma in which were scattered magnetite and apatite. The feldspar inclosed a great deal of the glass in sharply defined cavities, and also inclosed less apatite and magnetite. The hypersthene inclosed a much greater amount of magnetite and apatite and a much smaller amount of glass,

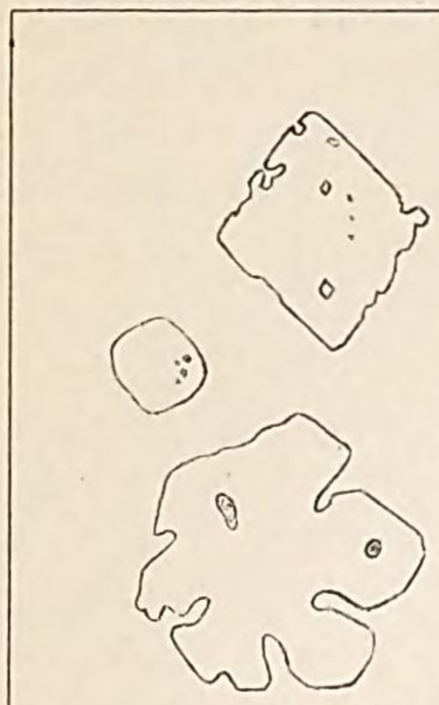
[1] Collection of the Fortieth Parallel Survey, No. 989 (22940).

[2] Ibid., No. 994 (22946).

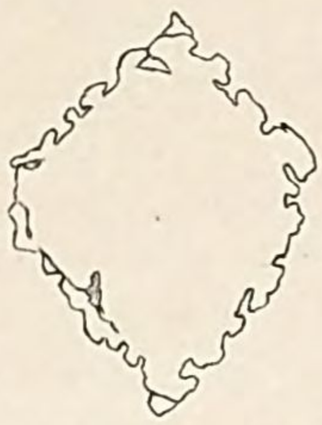
[3] Ibid., No. 1067 (23043).

[4] Volcanic Rocks of the Republic of Salvador, Central America. By Arnold Hague and J. P. Iddings. Am. Jour. Sci., July, 1886., vol. 32, pp, 26-31.

[5] Collection of the Fortieth Parallel Survey, No. 1044 (23017).



1.



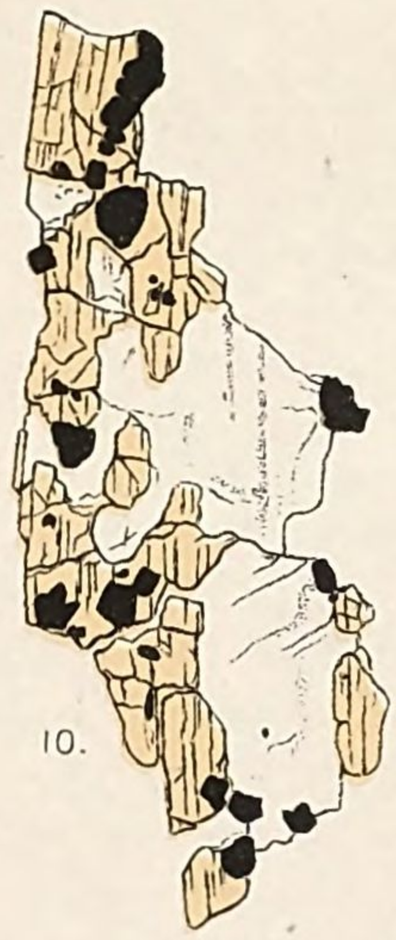
2.



3.



4.



10.



6.



7.



8.



5.



9.

Geo. S. Harris & Sons Lith. Phila.

INTERGROWTHS OF MINERALS IN GLASSY ROCKS.
AND QUARTZ PHENOCRYSTS.

which is scarcely recognizable as such. The boundary lines between the plagioclase and hypersthene are irregular and in places distinct. Where the two minerals wedge out against each other in the section there is no line of demarkation between them, and the color of the hypersthene fades out gradually.

From the cases of conjoint crystallization of various rock-making minerals in pumiceous glassy lavas, which are of very widespread occurrence, and from the similar intercrystallization of these minerals in the holocrystalline stock rock at Electric Peak, where the various phases of intergrowth can be studied and its primary nature established, it is apparent that caution should be used in referring other instances of parallel intergrowth in coarsely granular rocks to paramorphic actions. It would seem as though the presence of idiomorphic outlines would be necessary to determine the primary or secondary nature of the mineral in doubt where the rock exhibited no signs of secondary alteration. In cases where augite is surrounded by or appears to pass into compact hornblende, and neither mineral exhibits its characteristic crystal outline in any part of the rock under investigation and the rock is unaltered, the primary or secondary nature of either mineral may be questioned; for each mineral may be the result of the primary crystallization of the once molten magma, from which either of the two minerals may separate before the other, or either may be the result of the alteration of the other, since the change of compact hornblende to compact augite occurs in the rocks already described. It is probable, however, that the study of a series of varieties of the rock in any case would determine whether the intergrowth of the two minerals in a particular case is the result of primary crystallization from a molten magma, or of paramorphic action subsequent to the consolidation of the magma.

Alteration products.—Among the secondary minerals that are found in some of the rock sections from Electric Peak is uralite. Its derivation from original pyroxene is evident from the outline of the cross sections. It is usually accompanied by other signs of alteration in the rock, and is distinguishable from the primary brownish green hornblende. In some sections there is secondary acicular amphibole, light green and generally in confused aggregates. Besides these are chlorite, epidote, quartz, and calcite in the usual association. But as already observed, most of the thin sections exhibit no signs of decomposition. As the processes of decomposition are like those commonly observed in other rocks they need no special comment.

II (*b*). *Varieties of the stock rocks in which the amount of the light colored minerals* (*feldspar and quartz*) *exceeds that of the dark colored minerals* (*ferromagnesian silicates*) *and in which the quartz is not excessive.*—This group presents a more feldspathic facies of the diorite, and includes varieties that occur as lighter colored portions of the main mass without any apparent relation to its form, others that appear to be contact facies of the stock, and some that occur as dikes or veins in the main mass of diorite.

They are not grouped according to their mode of occurrence, but on mineralogical and microstructural grounds. They agree in having a preponderance of feldspar, with considerable quartz, and a range of ferromagnesian silicates that connects them with the diorites of Group II (*a*). They resemble the main body of diorite in general habit, but are lighter colored. The finer grained varieties approach the dike rocks in microscopical characters, and are probably intimately related to them geologically.

The hornblende, pyroxene, and biotite have the same characteristics as those in the main body of diorites, and require no further comment. They exhibit the same relationship to one another when found together. But since the rocks brought within this group are not from the same geological body, there is a greater variation in the relative proportion of the ferromagnesian silicates, as will be seen in Tables V and VI. The feldspars are more alkaline than those in the main body of diorite and have a somewhat different habit. The quartz also plays a slightly different rôle. Owing to the difference in microstructure it is not possible to compare the grain of these varieties directly with the grain of the less feldspathic diorites. But they can be correlated approximately. The coarsest grained variety, No. 215, of this group, grade 39, is from a light colored vein 1 foot wide, cutting the darker colored diorite. It is composed of broad plagioclase feldspars from 1^{mm} to 2^{mm} long, with numerous small and irregularly shaped quartz grains, located along the line of junction of the feldspars; green and brown hornblende and biotite are present in very irregularly shaped individuals, besides some magnetite and apatite. The hornblende is in part phenocrystic.

The feldspar has distinct zonal structure and polysynthetic twinning. The extinction angles are not very high and may belong to oligoclase or andesine. There are no characteristic inclusions. The quartz contains numerous fluid inclusions.

When the grain of the rock becomes smaller, as in the next three grades, Nos. 214, 213, and 212, the feldspars stand out more prominently as phenocrysts; they are more nearly idiomorphic and there is a greater amount of small grains of feldspar and quartz. The greater part of the ferromagnesian silicates is found intergrown with these small grains of feldspar and quartz, and appears to be later than the crystallization of the large feldspars. There are some porphyritical hornblendes which appear to belong to an earlier period of crystallization than those just mentioned. Small augites occur in No. 212, independent of the hornblende. The next specimen in the table is clearly a more feldspathic and quartzose facies of the main diorite. It exhibits the same structure, and the pyroxene and hornblende are intergrown in the same manner as in that rock. The next specimen in this series, No. 210, is considerably finer grained, being about grade 27. It is from a contact with the sedimentary rocks. The microstructure is like that of the coarser grained varieties, except that the large feldspars and hornblendes are distinctly idiomorphic, and the amount of granular material

about equals that of the phenocrysts. There is an approach to idiomorphism on the part of some of the individuals of the groundmass, more frequently the feldspars. Occasionally the same quartzes have a rudely idiomorphic form, and yield sections that indicate their occurrence in dihexahedral pyramids without the facies in the prism zone. The outlines of these sections are not sharply crystallographic, but are indented by the interference of adjacent and smaller feldspar grains. These quartzes carry fluid inclusions and individualized inclusions which sometimes have the shape of glass inclusions but appear to be feldspar. A slightly different groundmass structure is developed in a light colored apophysis of the stock, No. 209, grade 21. It is distinctly porphyritic, with abundant feldspars and numerous brown hornblendes. The groundmass in places exhibits a micropegmatitic structure.

The finest grained variety of contact facies in this group is No. 207, from near the sedimentary rocks. It has a fine grained groundmass similar to that of the last contact facies mentioned, No. 210, but is about grade 20. The porphyritical feldspars and hornblendes are not so abundant, and the latter are surrounded by shreds of biotite which appear to be nearly contemporaneous with the crystallization of the groundmass.

In this group have been placed two specimens: One, No. 208, from a dike on the southeast spur of Electric Peak, and the other, No. 206, from the talus directly below the first one. They resemble the varieties just described in the structure of the groundmass and in the occurrence of the biotite as a product of the final crystallization of the magma. They are slightly decomposed. From the same talus slope were collected two varieties, Nos. 204 and 205, which are very similar to those just mentioned, but are fresher. It is not known whether they are contact facies of the stock rock or dikes. A still finer grained variety, No. 203, occurs in small dikes near the stock on the northeast spur. The groundmass is a finely granular mixture of quartz and feldspar, with phenocrystic plagioclases and hornblende, and irregular patches of biotite.

II (*c*). *Varieties in which the amount of the light colored minerals (feldspar and quartz) exceeds that of the dark colored minerals (ferromagnesian silicates) and in which the quartz is abundant.*—This group presents very quartzose as well as feldspathic varieties of the diorite, which approach granite in composition and structure. They are mostly coarse grained dikes or veins that cut the main body of diorite and range from grade 35 to 40, Table VII. With them are placed the rocks from several narrow dikes in the sedimentary strata, which appear to be quartzose apophyses from the pyroxene-bearing magmas.

The rocks of this group are very similar to those of Group II (*b*), but are richer in quartz and the majority of the feldspars appear to be more alkaline; they have lower extinction angles and lower double refraction, and do not exhibit so great a number of twin lamellæ as the plagioclases of the dark colored diorite. Zonal structure is pronounced and the individuals are oftener equidimensional.

In the coarsest grained varieties they are allotriomorphic. There are a number of different species of feldspars present in these rocks, and their relative proportions vary. Occasionally there are those with abundant twin lamellæ, high double refraction and extinction angles, which are more nearly idiomorphic and rectangular. These appear to belong to the labradorite series. In some varieties of the rock there is considerable unstriated, allotriomorphic feldspar, without zonal structure, and with a distinct cleavage, that also bears thin lamellæ of another feldspar as inclusions parallel to the vertical axis, which is undoubtedly orthoclase. It is very abundant in No. 222, which is, in fact, a fine grained granite. It is shown in Pl. XLIX, Fig. 1, natural size. This occurs as a large body in the diorite, probably in the form of a dike or vein; it was not found in place, but as large slabs among those of diorite at the base of the high mass of diorite needles on the northeast spur of Electric Peak. The other varieties are more properly quartz-diorites.

In the coarsest varieties of this group the ferromagnesian silicates are biotite and hornblende, with no pyroxene. The biotite is in excess of the hornblende.

II (c'). The remaining rocks in this group are from narrow apophyses in the immediate vicinity of the main stock. They are rich in quartz, but carry more basic plagioclases and a variable amount of augite, besides biotite and hornblende. They appear to be quartzose facies of the pyroxene-diorite of the main stock and may be contemporaneous offshoots from it. No such variety of rock has yet been found cutting the main mass of the diorite.

The microstructure of Nos. 220 and 221 is somewhat finer grained than that of Nos. 222, 223, and 224; the relative amounts and the size of the quartz and feldspar are about the same. In No. 221 the biotite is largely in excess of the augite which occurs in small crystals and grains. Hornblende is entirely absent. In No. 220 there is very little pyroxene, more hornblende and still more biotite.

A much finer grained variety, No. 219, from the same locality is grade 25; it is distinctly porphyritic. The groundmass is composed of small grains of quartz and feldspar, through which are scattered abundant plagioclases with irregular outlines, high extinction angles and the dust-like inclusions that characterize the labradorites of the coarse grained diorite. There are large porphyritical hornblendes and considerable biotite with a small amount of pyroxene inclosed in the hornblende.

A very fine grained variety, Nos. 216, 217, and 218, about grades 19 and 24, resembles No. 221 in mineral composition. The ferromagnesian silicates are biotite and some augite. The groundmass is composed of small grains of quartz and feldspar. The distinguishing feature of the groundmass of the fine grained varieties of these quartzose rocks is the granular structure; that of the less quartzose ones is the aggregation of lath-shaped feldspars.

III. QUARTZ-MICA-DIORITE-PORPHYRITE.

The last magma to break through the conduit of Electric Peak was that of the quartz-mica-diorite-porphyrite. It forms a broad stock cutting up through the body of the diorite, wedging out to the north, and sending a number of narrow dikes into the sedimentary strata to the southwest. The rock is light gray to white, with abundant small phenocrysts of feldspar, quartz, and biotite. Its habit is similar to that of the other porphyrites, and is produced by the great number of small phenocrysts. The groundmass is scarcely recognizable as such macroscopically, except in the finest grained varieties. The rock appears to be evenly granular in hand specimens. The coarsest grained varieties are from the stock, the finest grained from the narrow dikes on the southeast spur of Electric Peak. The varieties are arranged in Table VIII, column III, according to their grade of crystallization.

Besides biotite there is a little hornblende, which is a prominent constituent of one modification of the rock, shown in Fig. 2, Pl. XLIX, but is almost entirely wanting in the greater portion of the rock. It occurs as small inclusions in some of the large feldspars. In most of the specimens collected the biotite is partly chloritized and the feldspars are more or less altered.

The rock is intermediate, between quartz-diorite-porphyrite and granite-porphyry. It varies slightly in mineral composition as well as in chemical composition, and the extremes would be classed under these two heads.

The finest grained varieties which occur in the narrow dikes consist of a microcrystalline groundmass of irregular grains, whose exact nature can not be determined optically, but which are undoubtedly quartz and feldspar, as these minerals make up the groundmass of the coarser grained varieties. Through this groundmass are scattered phenocrysts of feldspar and quartz, with biotite and occasionally hornblende. The feldspar is mostly plagioclase, with polysynthetic twinning, and appears to belong to the oligoclase series. A few individuals exhibit no striations and may be orthoclase. Their form is distinctly idiomorphic when the grain of the groundmass is extremely fine, but where this is somewhat larger the outline of the feldspar section is not so sharp.

The porphyritical quartz is in smaller individuals than the feldspar. Most of them exhibit straight edged crystallographic outlines, that belong to dihexahedral pyramids, possibly with small prism faces. Others are rounded more or less completely. Straight edged and rounded grains occur indiscriminately through the rock and in the same rock section. (Pl. LI, Fig. 1.) Some individuals exhibit irregular outlines occasioned by bays or pockets of the groundmass penetrating the quartz substance. These pockets are extremely abundant around some individuals and are entirely absent from others. They occur both in straight edged and rounded individuals. They are often associated with numerous microcrystalline inclusions that are located along the margin of the quartzes. From their mode of occurrence in otherwise idiomorphic

quartzes it seems probable that in these instances they are forms of original inclusions and not the result of a corrosive action of the magma on the idiomorphic quartzes. There are also microcrystalline dihexahedral inclusions within the quartzes, and gas and fluid inclusions.

In the finest grained varieties of this rock the outline of the quartz individuals is sharply defined against the groundmass, but in the slightly coarser grained varieties this is not the case with all of the individuals. Some have rough surfaces which are evidently produced by the substance of the porphyritical quartz extending irregularly into the groundmass. In some cases there is a narrow border of groundmass around the quartz, part of which extinguishes light in unison with the porphyritical quartz. The quartz in this border of groundmass is evidently oriented parallel to the large quartz grain.

The biotite in these varieties of the rock is almost completely decomposed to chlorite with some epidote and rutile needles. The rock contains a few grains of magnetite and crystals of apatite.

The quartz-mica-diorite-porphyrite occurring in the stock is much coarser grained than that just described from the narrow dikes. It is much richer in phenocrysts, which are larger and so crowded together that there is very little groundmass between them. The coarsest grained variety is about grade 35. The feldspars have the same characters as those just described. The quartz is particularly interesting; some individuals are quite large, and the sections of these are usually sharp edged; they are partly rounded, partly crystallographically bounded, the two forms occurring together in the same thin section. The greater number of quartzes are irregularly outlined, with an approach to a dihexahedral shape, which is less noticeable as the groundmass becomes coarser grained. The inclusions are the same as in the quartzes of the finest grained varieties. These inclusions are sometimes arranged in a zone which marks a central core of idiomorphic quartz, the outer portion of the individual being less regularly defined and extending into the surrounding groundmass a short distance. In the coarsest grained varieties the forms of most of the quartzes are very irregular and allotriomorphic, the nature of their inclusions being about the same. A few are somewhat idiomorphic. The small grains of quartz in the groundmass are wholly allotriomorphic. The variation in the quartzes is illustrated by Figs. 2 and 3, Pl. LI, the former occurring in a medium grained variety, No. 231, grade 21, and the latter in the coarsest grained form, No. 238, grade 35. The quartz individual represented by Fig. 3 exhibits only a slight approach to a dihexahedral shape. It is drawn with its principal axis, c, in the vertical position, which may be recognized in the drawing by the position of several dihexahedral inclusions.

It is evident that in this rock the porphyritical quartzes were the last of the phenocrysts to crystallize and that their crystallization in the coarser grained varieties continued into the period of the crystallization of the groundmass with no marked evidence of interruption.

GENERAL CONSIDERATION OF THE MINERAL AND CHEMICAL COMPOSITION OF THE INTRUSIVE ROCKS; THEIR VARIABILITY AND OVERLAPPING, AND THE ABSENCE OF DEFINITE TYPES.

Mineral composition.—The accompanying tables are designed to express some of the variations that exist in the rocks under investigation. They are, of course, approximate determinations in every case, and represent the judgment of the writer. It is probable that another observer might differ, in particular instances, as to the position of a rock in any of the columns, but this difference would not be very material and would not affect the general result.

In considering the group of dike rocks described under Group I and the dikes of Group III the most essential variation is among the phenocrystic minerals and in the accompanying groundmass structures, the variations in the grain of the groundmass being of secondary importance. They have, therefore, been arranged in Table III according to the variable ferromagnesian phenocrysts they contain, no account being taken of the feldspars since their variation is much less marked and not easily recognized. It is to be remembered that they are present in all of the rocks, and are more basic in the basic rocks than in the acidic.

In Table III no account is taken of the degree of crystallization. This is expressed in Table IV, where the same rocks are correlated as closely as possible according to the grain of the groundmass, the finest grained being at the top and the coarsest at the bottom of the table.

TABLE III.—*Mineral variation in the dike rocks of Electric Peak.*

Mineral groups.	Specimen numbers.	Phenocrysts other than feldspar.			
		Pyroxene.	Hornblende.	Biotite.	Quartz.
d_1	136	much.	.....	.....	.....
	137	much.	.....	.....	.....
d_2	138	much.	some.	.....	.....
d_3	139	much.	much.	.....	.....
d_4	140	some.	much.	.....	.....
	141	some.	much.	.....	.....
d_5	142	.....	much.	.....	.....
	143	.....	much.	.....	.....
d_6	144	.....	much.	little.	.....
	145	.....	much.	little.	.....
	146	.....	much.	little.	.....
	147	.....	much.	little.	.....
	148	.....	much.	little.	.....
	149	.....	much.	little.	.....
d_7	150	.....	much.	some.	.....
	151	.....	much.	some.	.....
	152	.....	much.	some.	.....
d_8	153	.....	much.	much.	.....
	154	.....	much.	much.	.....
	155	.....	much.	much.	.....
	156	.....	much.	much.	.....
	157	.....	much.	much.	.....
	158	.....	much.	much.	.....
d_9	160	.....	some.	much.	.....
	161	.....	some.	much.	.....
	159	.....	little.	much.	.....
d_{10}	162	.....	little.	much.	little.
d_{11}	163	.....	little.	much.	much.
	164	.....	little.	much.	much.
	165	.....	little.	much.	much.
	166	.....	little.	much.	much.
	167	.....	little.	much.	much.
	168	.....	little.	much.	much.
	169	.....	little.	much.	much.

From Table III it is seen that the dike rocks vary in mineral composition from acidic rocks with much porphyritical quartz and biotite and very little hornblende, through intermediate rocks with much porphyritical biotite and hornblende, to basic rocks with pyroxene and little or no porphyritical hornblende and biotite, but which are more coarsely crystalline than the more acid rocks and contain some biotite which appears to belong to the period of final consolidation and to be related to the biotite in the diorites. The gradual nature of the transition from one extreme to the other is apparent.

The impossibility and impracticability of considering certain rocks as definite types with which to compare other rocks in the region is also evident when it is observed that the mineralogical variation takes place within certain limits in one rock body (specimens Nos. 159, 160, 161, 154, and 151 are from the same dike); and that what appears to be a mineralogical facies of one particular rock body is the characteristic combination of another, and its facies is something different. Field observation shows that in this locality the greater number of dikes are composed of rocks carrying variable percentages of porphyritical hornblende and biotite, and that the other varieties are less numerous. In another region other varieties predominate. The chemical variations which are indicated by the silica percentages range from 57·12 in subdivision d_3 to 61·85 in d_7, and probably reach 69·00 in d_{11}. They indicate the correspondence between the mineralogical and chemical variations for this group of rocks.

TABLE IV.—*Grades of crystallization of the dike rocks of Electric Peak.*

Grades of crystallization.	Mineralogical grouping indicated in Table III.										
	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}	d_{11}
6											163
7						144					164, 165
8					142						166, 167
9						145, 146				162	168, 169
10						147	150				
11						148, 149			159, 160		
12					143			153, 154	161		
13								155			
14							151, 152	156, 157			
16			139					158			
19	136			140, 141							
20	137										
25		138									

Table IV expresses the range in degree of crystallization of the groundmass of these rocks, which are arranged in columns corresponding to the mineralogical grouping of Table III. It is to be remarked that the specimens were collected from different sized dikes and from different parts of the dikes, so that the variations in grain can not be compared very closely with the mineral composition. But when the size of the dikes in each case is taken into consideration it becomes even more evident than from the table that the coarseness of grain bears a very considerable relation to the chemical composition of the rock. The

variation in grain between the sides and center of a dike and between dikes of different widths, for rocks of nearly the same composition, is not so great as the variation between rocks of different composition where the size of the dikes in which they occur is somewhat similar. Thus, specimen No. 137 is from the center of a 4-foot dike, and No. 136 from the contact wall of the same,and specimen No. 151 is from the center of an 8-foot dike, and Nos. 161 and 154 from the contact walls of the same; Nos. 168 and 169 are from 4-foot dikes, and No. 167 from a 2-foot dike. They all occur at nearly the same altitude, but it is possible that the pyroxene-bearing rock, No. 137, may have been intruded in rocks which were more heated at the time of its intrusion and so have acquired its decree of crystallization through slower cooling, but this is not so likely to have happened in the case of rock No. 138, which is in the same part of the mountain as No. 139, but is in a dike 10 feet wide and is very much coarser grained than No. 137. (See Table VI.)

The groundmass of the rock with porphyritical quartz and biotite, No. 169, is made up of minute grains of quartz and feldspar about $0{\cdot}015^{mm}$ in diameter, while the groundmass of pyroxene-bearing variety, No. 137, is made up of lath-shaped and irregularly shaped feldspar about $0{\cdot}10^{mm}$ to $0{\cdot}14^{mm}$ in length, and the groundmass of No. 138 is composed of lath-shaped feldspars $0{\cdot}5^{mm}$ to $0{\cdot}7^{mm}$ in length.

The character of the groundmass changes from an even granular structure in the acidic rocks, through one made up of irregular grains and lath-shaped feldspars in the intermediate rocks, to an aggregation of lath-shaped feldspars with almost no irregular grains in the basic varieties.

The tendency of basic rocks to crystallize more completely and with larger groundmass crystals than acidic rocks is constantly observed among the effusive rocks, such as basalts, andesites, and rhyolites. The same law appears to obtain among the intrusive rocks. It is of course necessary to compare rocks that appear to have crystallized under very nearly the same physical conditions.

The rocks of Group II have been described in greater detail on account of their number and importance and have been subdivided into three subgroups, II (a), II (b), II (c), page 597. The tables presenting the results of this part of the work have a different form and are arranged separately for each subdivision. They are Tables V, VI, and VII.

TABLE V.—*Mineralogical variation among the diorites of Group II (a).*

Specimen number.	Percentage of silica.	Amount of quartz.				Relative amount of pyroxene and hornblende.					Relative amount of pyroxene, hornblende, and biotite.			
		Little.	Moderate.	Considerable.	Much.	*p*.	*p*>*h*.	*p*=*h*.	*p*<*h*.	*h*.	(*ph*).	(*ph*)>*b*.	(*ph*)=*b*.	(*ph*)<*b*.
170	.....	170	.....	.....	.....	170	.....	.....	.....	.....	170		.....	.....
171	57·38	.....	171	.....	.....	171	.....	.....	.....	.....	.....	171	.....	.....
172	.....	.....	172	.....	.....	172	.....	.....	.....	.....	.....	172	.....	.....
173	.....	.....	173	.....	.....	173	.....	.....	.....	.....	.....	173	.....	.....
174	.....	.....	174	.....	.....	174	.....	.....	.....	.....	.....	174	.....	.....
175	.....	.....	175	.....	.....	.....	175	.....	.....	.....	.....		175	.....
176	61·22	176		.....	.....	.....	.....	176	.....	.....	.....		176	.....
177	58·05	177	.....	.....	.....	.....	177	.....	.....	.....	.....		177	.....
178	56·33	178	.....	.....	.....	.....	178	.....	.....	.....	.....	178	.....	.....
179	.....	.....	.....	179	.....	.....	.....	179	.....	.....	.....	.....	179	.....
180	58·10	.....	180	.....	.....	.....	.....	180	.....	.....	.....	.....	180	.....
181	.....	.....	.....	181	.....	.....	.....	181	.....	.....	.....		181	.....
182	.....	.....	.....	182	.....	.....	.....	182	.....	.....	.....		182	.....
183	.....	.....	.....	183	.....	.....	.....	.....	183	.....	.....		183	.....
184	.....	.....	.....	184	.....	.....	.....	.....	184	.....	.....	.....	184	.....
185	58·11	.....	.....	185	.....	.....	.....	.....	185	.....	.....		185	.....
186	58·87	.....	186	.....	.....	.....	.....	186	.....	.....	.....	.....	186	.....
187	.....	.....	187	.....	.....	.....	.....	.....	187	.....	.....		187	.....
188	.....	.....	.....	188	.....	.....	.....	.....	188	.....	.....		188	.....
189	55·64	.....	189	.....	.....	.....	.....	189	.....	.....	.....	.....	189	.....
190	.....	.....	190	.....	.....	.....	.....	.....	190	.....	.....		190	.....
191	.....	.....	.....	191	.....	.....	.....	.....	191	.....	.....	.....	191	.....
192	.....	.....	.....	192	.....	.....	.....	.....	192	.....	.....	.....	192	.....
193	.....	.....	.....	193	.....	.....	.....	.....	193	.....	.....		193	.....
194	.....	.....	.....	194	.....	.....	.....	.....	.....	*194	.....	.....	194	.....
195	.....	.....	.....	195	.....	.....	.....	.....	195	.....	.....		195	.....
196	.....	196	.....	.....	.....	.....	.....	.....	196	.....	.....	196	.....	.....
197	56·28	.....	197	.....	.....	.....	.....	197	.....	.....	.....		197	.....
198	.....	198	.....	.....	.....	.....	.....	.....	198	.....	.....	.....	198	.....
199	53·72	199	.....	.....	.....	.....	.....	.....	.....	*199	.....	199	.....	.....
200	55·23	200	.....	.....	.....	.....	.....	200	.....	.....	.....	.....	200	.....
201	.....	.....	201	.....	.....	.....	.....	.....	201	.....	.....		201	.....
202	.....	.....	202	.....	.....	.....	.....	202	.....	.....	.....		202	.....

* The hornblende in these rocks is in part secondary, pyroxene may have been present originally.

TABLE VI.—*Mineralogical variation among the diorites of Group II (b).*

Specimen number.	Percentage of silica.	Amount of quartz.				Relative amount of pyroxene and hornblende.					Relative amount of pyroxene, hornblende, and biotite.			
		Little.	Moderate.	Considerable.	Much.	*p*.	*p*>*h*.	*p*=*h*.	*p*<*h*.	*h*.	(*ph*).	(*ph*)>*b*.	(*ph*)=*b*.	(*ph*)<*b*.
203	.....	.....	.....	203	.....	.....	.....	.....	.....	203	.....	203	.....	.....
204	.....	.....	.....	204	.....	.....	.....	.....	.....	204	.....		204	.....
205	65·60	.....	.....	205	.....	.....	.....	.....	205		.....		205	.....
206	.....	.....	206	.....	.....	.....	.....	.....	.....	206	.....	.....	206	.....
207	65·94	.....	.....	207	.....	.....	.....	.....	.....	207	.....	207	.....	.....
208	.....	.....	.....	208	.....	.....	.....	.....	.....	208	.....	.....	208	
209	63·78	.....	.....	209	.....	.....	.....	.....	.....	209	.....	209	.....	.....
210	.....	.....	.....	210	.....	.....	.....	.....	.....	210	.....		210	.....
211	64·07	.....	211		.....	.....	.....	*211	.....	.....	.....	.....	211	.....
212	.....	.....	.....	212	.....	.....	†212	.....	.....	.....	.....	.....	212	.....
213	65·11	.....	.....	213	.....	.....	.....	.....	213	.....	.....	.....	213	.....
214	.....	.....	214		.....	.....	.....	.....	214	.....	.....		214	.....
215	64·85	.....	.....	215	.....	.....	.....	.....	.....	215	.....	215	.....	.....

* This rock belongs with 192, resembles it in structure and character, but is higher in silica and feldspar.

† An exceptional variety, from talus.

TABLE VII.—*Mineralogical variation among the diorites of Group II (c).*

Specimen number.	Percentage of silica.	Amount of quartz.				Relative amount of pyroxene and hornblende.					Relative amount of pyroxene, hornblende, and biotite.			
		Little.	Moderate.	Considerable.	Much.	*p*.	*p*>*h*.	*p*=*h*.	*p*<*h*.	*h*.	(*ph*).	(*ph*)>*b*.	(*ph*)=*b*.	(*ph*)<*b*.
216	.....	.....	.....	.....	216	*216	.....	.....	.....	.....	.....	.....	216	
217	.....	.....	.....	.....	217	217	.....	.....	.....	.....	.....	.....	.....	217
218	.....	.....	.....	.....	218	218	.....	.....	.....	.....	.....	.....	.....	218
219	65·48	.....	.....	.....	219	.....	.....	.....	219	.....	.....	219	.....	.....
220	65·80	.....	.....	.....	220	.....	.....	.....	220	.....	.....	.....	.....	220
221	.....	.....	.....	.....	221	221	.....	.....	.....	.....	.....	.....	.....	221
222	.....	.....	.....	.....	222	.....	.....	.....	.....	222	.....	.....	.....	222
223	67·54	.....	.....	.....	223	.....	.....	.....	.....	223	.....	.....	.....	223
224	.....	.....	.....	.....	224	.....	.....	.....	224	.....	.....	.....	.....	224
225	.....	.....	.....	.....	225	.....	.....	.....	.....	225	.....	.....	.....	225
226	.....	.....	.....	.....	226	.....	.....	.....	.....	226	.....	.....	.....	226
227	66·05	.....	.....	.....	227	.....	.....	.....	.....	227	.....	.....	227	

* The first six rocks in this group are closely related to the main mass of the diorite of Group II (*a*).

Table V presents those varieties of the stock rocks in which the amount of the ferromagnesian silicates about equals that of the feldspar and quartz combined. There is no distinction made as to whether the crystals occur as phenocrysts or not. They are arranged in a series according to their degree of crystallization, the finest grained being at the top, the value of the degrees of crystallization having been already explained (p. 599). The silica percentage is given in all cases where it has been determined. In the table an attempt is made to express the relative amounts of the quartz, of the hornblende and pyroxene, and of the biotite and hornblende and pyroxene. The relative amount of feldspar is not expressed. In a general way it varies inversely as the amount of quartz for this subgroup. The columns under the different divisions of the table express certain relations of the minerals approximately. Under the divisions of quartz, the terms "little," "moderate," "considerable," "much," are only used as comparative terms applicable to this group of rocks throughout its three subdivisions, II (*a*), II (*b*), II (*c*), and have no reference to the relative amount of quartz which might be found in another suite of rocks. Consequently what would be considered "much" quartz in these rocks might only be a moderate amount for another series.

Under the division which shows the relative amounts of pyroxene and hornblende in each rock, the first column, "p," indicates that there is pyroxene and no hornblende; the next column, that the pyroxene is in excess of the hornblende; the third, that they are equal, and so on. The relative amounts of pyroxene or of hornblende in any two varieties of the rock is not indicated directly. It can be ascertained roughly by considering that in this subgroup the sum of the pyroxene, hornblende, and biotite is nearly constant.

In the next division of the table the amount of the biotite is compared with that of the pyroxene and hornblende combined, in the manner already explained for the previous division.

The first fact brought out by a study of this table is the variability of the quartz percentage, which does not appear to hold a very definite relation to the silica percentage, as in the case of Nos. 185 and 186. But it is observed in studying the thin sections that the quartz is not so noticeable in the fine grained varieties as in the coarse grained ones, and may therefore be either overlooked or possibly not so strongly developed. Thus the coarse grained varieties with little quartz are lower in silica than the fine grained varieties with little quartz. (Compare Nos. 199 and 200 with Nos. 176, 177, and 178.) It is, of course, evident that in rocks with variable percentages of the essential minerals which are all silicates there can be no rigid relation between the proportion of any one of these minerals and the silica percentage of the rock within the narrow range of chemical variation that occurs in this group. In it the silica does not vary 7 per cent, and the amount of the other chemical constituents are the controlling chemical factors. This will be discussed more fully when the chemical composition of the rocks is considered.

The most regular variation is in the relative proportions of pyroxene and hornblende. There is a definite increase in the amount of hornblende and decrease in that of pyroxene as the rock becomes coarser grained. This is specially noticeable in those specimens forming series from one spot, Nos. 172, 173, 174, 175, 183, and 191, and Nos. 181, 182, 185, 188, and 193. The variation in the relative amount of biotite is not so marked, but there is a slight increase from the fine grained to the coarse grained end of the series.

The irregularities in the variations of the different minerals could be better understood if the chemical composition of all of the different varieties of the rocks were known, but such an investigation is not practicable. The rocks of this subgroup may be classed among the pyroxene-diorites and quartz-pyroxene-diorites. They carry considerable biotite, and pass into quartz-mica-diorite at one end of the series and into pyroxene-porphyrite at the other.

Tables VI and VII include those varieties of rock in which the amount of feldspar and quartz together exceeds that of the ferromagnesian silicates, and Table VII includes those varieties particularly rich in quartz.

The silica percentage is considerably higher in these rocks than in those of the previous subgroup. The quartz is more uniform, and on the whole is higher. It is very considerably higher in Subgroup II (*c*). Pyroxene is absent from most of the varieties, but occurs in small amounts without hornblende in a few instances already noticed. Biotite is more variable in Subgroup II (*b*) than in II (*c*), where it is the predominant ferromagnesian silicate.

The relation of quartz, biotite, hornblende, and pyroxene to the chemical composition of the different varieties of this series of rocks is not so definite as in the case of the group of dike rocks. In general, quartz

and biotite are more abundant in the more acidic varieties of the coarse grained rocks, but they both appear in the basic varieties when they are coarsely crystalline. The relations of horneblende and pyroxene to the chemical composition of rocks is not elucidated in any way by the study of this group of rocks. It is evident, however, that in the case of the intrusive rocks of this region hornblende is developed to a greater extent in the basic rocks as they are coarser grained, and that pyroxene is more abundant in the finer grained forms than in the coarser.

The mineral composition of the quartz-mica-diorite-porphyrite, Group III, is very uniform, and needs no tabulation. It contains very much quartz, abundant biotite, and almost no hornblende; the greater part of the rock is more siliceous than the main body of the diorite, and reaches 69·24 per cent of silica, but a facies of it, which is richer in hornblende than the body of the rock, has only 65·97 per cent of silica.

TABLE VIII.—*Grades of crystallization of the dike and stock rocks of Electric Peak.*

Grade.	I.	II (*a*).	II (*b*).	II (*c*).	III.
	$d_{1\text{-}10}$.	s_1.	s_2.	s_3.	s_4 and d_{11}.
6	.....	.....	.....	.....	163
7	144	.....	.....	.....	164, 165
8	142	.....	.....	.....	166, 167
9	143; 145, 146	.....	.....	.....	168, 169
10	147, 150	.....	.....	.....	.....
11	148, 149; 159, 160	.....	.....	.....	.....
12	143, 153; 154, 161	.....	.....	.....	.....
13	155	170	.....	.....	.....
14	151, 152; 156, 157	171	.....	.....	.....
15	.....	172	.....	.....	.....
16	139, 158	173	.....	.....	.....
17	.....	174	203	.....	.....
18	.....	.....	204, 205	.....	.....
19	136; 140, 141	.....	206	216, 217	.....
20	137	.....	207, 208	.....	228, 229
21	.....	.....	209	.....	230, 231
22	.....	175	.....	.....	232, 233
23	.....	176	.....	.....	234, 235
24	.....	177, 178	.....	218	236
25	138	.....	.....	219	237
26	.....	179, 180	.....	.....	.....
27	.....	181	210	.....	.....
28	.....	182	.....	.....	.....
29	.....	183	.....	.....	.....
30	.....	184, 185	.....	.....	.....
31	.....	186, 187	.....	.....	.....
32	.....	188	.....	.....	.....
33	.....	189; 190, 191	.....	.....	.....
34	.....	192	211	.....	.....
35	.....	193	212	220	238
36	.....	.....	213	221	.....
37	.....	194	.....	222; 223, 224	.....
38	.....	195	214	.....	.....
39	.....	196	215	.....	.....
40	.....	197	.....	225; 226, 227	.....
41	.....	198	.....	.....	.....
42	.....	199	.....	.....	.....
43	.....	200	.....	.....	.....
44	.....	201	.....	.....	.....
45	.....	202	.....	.....	.....

Table VIII expresses the relative degree of crystallization of all the intrusive rocks collected from the stock and dikes of Electric Peak. They are arranged in the groups already described. The breaks in the different columns do not signify breaks in the gradation of crystallization in the rock bodies in the field, but simply that the specimens collected are not from all the different structural phases of the different rocks. However, the clustering of the numbers in particular parts of the scale indicates the prevailing grain of the rocks as they are exposed at the present time.

It is not possible to draw a line of demarcation anywhere in the scale based on the degree of crystallization between rocks that occur in narrow dikes and those that form parts of much larger bodies. A relation between the degree of crystallization and the size of the rock body does not at first appear when all of these occurrences are considered together. The very important influence of several other factors, however, becomes apparent. One is the chemical character of the magma, the more basic magmas tending to crystallize coarser than more siliceous ones under similar physical conditions. Another factor is the previous temperature of the rocks into which the molten magmas were injected, and the consequent differences in the rate of cooling which the molten magmas experience. There may also be other factors which influence the crystallization in certain cases, but they are not evident in the occurrences at Electric Peak. In this locality the chief factor influencing the crystallization appears to have been the temperature of the inclosing rocks at the time of the different intrusions. The next most influential factor appears to have been the chemical character of the magma itself, and the third the size of the intruded mass. In another region the relative importance of these factors may be different.

Chemical composition.—The chemical composition of the intrusive rocks at Electric Peak is shown by the analyses in Table IX. Nos. 197, 171, 177, 215, 213, 205, 233, 227, 223, and 230 were made by Mr. J. E. Whitfield; Nos. 176 and 211 were made by Mr. W. H. Melville. All are from rocks occurring in the stock and its immediate apophyses. They represent the composition of various forms of the diorite and diorite-porphyrite. The first four analyses, Nos. 197, 171, 177, and 176, are from the main body of the stock, and belong to Subgroup II (*a*). The next four analyses, Nos. 211, 215, 213, and 205, are from facies of the main body of the diorite and from one of the lighter colored veins or dikes which traverse it. They belong to Subgroup II (*b*). Two more facies of the main stock are represented by analyses Nos. 227 and 223. They are quite siliceous, and belong to Subgroup II (*c*). Analyses Nos. 233 and 230 are from the large body of quartz-mica-diorite-porphyrite, the first being a basic facies of it, and the second corresponding more nearly to the general character of the body of the rock.

TABLE IX.—*Chemical analyses of intrusive rocks from Electric Peak.*

Specimen No.	197	171	177	176	211	215	213	205	233	227	223	230
SiO_2	56.28	57.38	58.05	61.22	64.07	64.85	65.11	65.60	65.97	66.05	67.54	69.24
TiO_2	.84	trace	1.05	.61	.45	.91	.71	.75	.42	.34	.80	.65
Al_2O_3	14.23	16.86	18.00	16.14	15.82	16.57	16.21	17.61	16.53	16.96	17.02	15.30
Fe_2O_3	4.69	2.49	2.49	3.01	3.40	2.10	1.06	.95	2.59	2.59	2.97	1.72
FeO	4.05	5.17	4.56	2.58	1.44	2.15	3.19	2.76	1.72	1.38	.34	.69
NiO	.....	.....	.....	.09	.05	.....	.....	.....	.....	.....	.....	.....
MnO	.16	trace	none	trace	trace	none	none	none	none	none	trace	trace
CaO	7.94	7.32	6.17	5.46	4.43	4.01	3.97	3.72	3.37	3.37	2.94	2.98
MgO	6.37	5.51	3.55	4.21	3.39	2.14	2.57	1.49	2.11	2.08	1.51	.95
Li_2O	.01	.39	none	.....	.....	none	.04	.03	.09	none	.03	none
Na_2O	2.98	3.33	3.64	4.48	4.06	3.71	4.00	4.36	3.41	4.20	4.62	4.46
K_2O	1.23	1.45	2.18	1.87	2.27	3.10	2.51	2,36	2.67	2.53	2.28	2.52
P_2O_5	.40	trace	.17	.25	.18	.14	.02	.16	trace	trace	trace	trace
SO_3	trace	.21	.07	.....	.....	trace	trace	trace	.13	.03	.26	.27
Cl	.17	.17	trace	.....	.....	none	none	none	.09	trace	.15	trace
H_2O	.93	.42	.86	.44	.52	.35	.94	.59	1.23	.69	.55	1.30
	100.28	100.70	100.79	100.36	100.08	100.03	100.33	100.38	100.33	100.22	101.01	100.08
Less O for Cl	.04	.04	.....	.....	.....	.....	.....	.....	.02	.....	.03	.....
	100.24	100.66							100.31		100.98	

TABLE X.—*Silica percentages of the rocks from Electric Peak.*

Sheet rocks.	Dike and stock rocks.					SiO_2.
	I.	II(*a*).	II(*b*).	II(*c*).	III.	
.....	.....	53.72	.....	.....	.....	53.72
.....	.....	55.23	.....	.....	.....	55.23
.....	.....	55.64	.....	.....	.....	55.64
.....	.....	56.28	.....	.....	.....	56.28
.....	.....	56.33	.....	.....	.....	56.33
.....	57.12	.....	.....	.....	.....	57.12
.....	.....	57.38	.....	.....	.....	57.38
.....	.....	58.05	.....	.....	.....	58.05
.....	.....	58.10	.....	.....	.....	58.10
.....	.....	58.11	.....	.....	.....	58.11
58.49	.....	.....	.....	.....	.....	58.49
.....	.....	58.87	.....	.....	.....	58.87
59.64	.....	.....	.....	.....	.....	59.64
.....	60.54	.....	.....	.....	.....	60.54
.....	.....	60.56	.....	.....	.....	60.56
.....	60.89	.....	.....	.....	.....	60.89
61.50	.....	.....	.....	.....	.....	61.50
.....	61.85	.....	.....	.....	.....	61.85
.....	.....	.....	63.01	.....	.....	63.01
.....	.....	.....	63.78	.....	.....	63.78
.....	.....	.....	64.85	.....	.....	64.85
.....	.....	.....	65.11	.....	.....	65.11
.....	.....	.....	.....	65.48	.....	65.48
.....	.....	.....	65.60	.....	.....	65.60
.....	.....	.....	.....	65.80	.....	65.80
.....	.....	.....	65.94	.....	.....	65.94
.....	.....	.....	.....	.....	65.97	65.97
.....	.....	.....	.....	66.05	.....	66.05
.....	.....	.....	.....	67.54	.....	67.54
.....	.....	.....	.....	.....	69.24	69.24

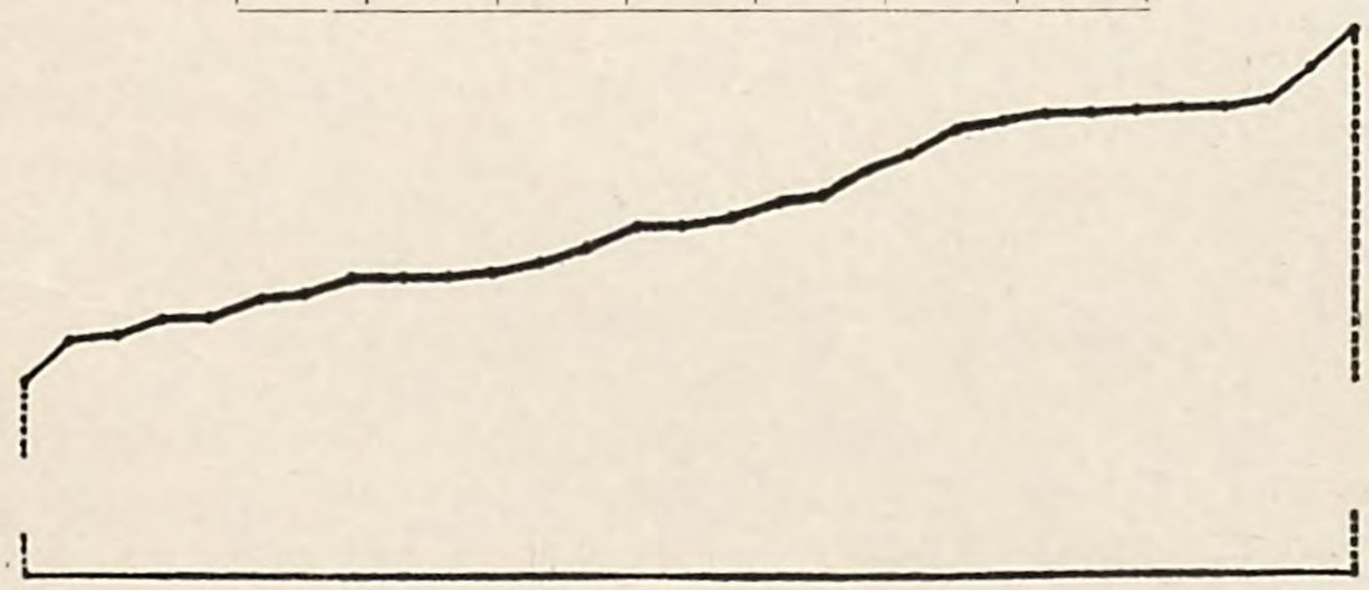


FIG. 79.—Variation of silica percentages.

The silica percentages of a number of varieties of these rocks were determined and are given in Table X, together with those from the complete analyses. In a measure they supplement these analyses and demonstrate what is evident from the microscopical study of the thin sections, namely: That the diorites and porphyrites pass through all possible gradations from one extreme to the other. The character of this transition is shown by the diagram, Fig. 79, in which each determination is given the same weight, the series is arranged according to the increase of silica, and the silica percentages are plotted as ordinates.

In Table X the percentages are all placed in the extreme right-hand column, and also in separate columns corresponding to the groups described in the first part of the paper. From this it is seen that the main body of the diorite varies from 53·72 to 60·56 per cent of silica, and in certain contact facies reaches 67·54 per cent. The dikes of later rocks related to the diorite and cutting the main body of the stock range from 63·78 to 69·24 per cent.

In the various bodies of magma that have followed one another through the conduit at Electric Peak, there is a variation in chemical composition in each, the different series of changes overlapping one another. Thus the average chemical composition of each subgroup of varieties shifts somewhat, and is more basic for one than another. But the end varieties of each subgroup overlap, so that the most basic modification of the more acidic group is more basic than the most acidic end of the more basic group which immediately preceded it.

Since the rocks of Group I belong to outlying dikes of the main stock and are contemporaneous with it, their silica percentages may be placed in the proper subgroup of the stock rocks, making subgroups II (*a*) and II (*b*) practically continuous. It appears from Table X that the succession of magmas which came up through the vertical fissures was from a basic one to more and more acidic ones, and that the previous intrusions which formed the sheet rocks were of a magma of medium chemical composition.

The variations of the other chemical constituents of these rocks are best comprehended by comparing their molecular proportions. This has been done graphically in the accompanying diagram, Fig. 80, in which the molecular proportions of the principal oxides are plotted as ordinates, those of the silica being taken as abscissas. The origin of abscissas is located some distance to the left.

The first impression derived from the diagram is that of the irregularity of the variations in all the oxides besides silica, especially in the magnesia. Moreover, these variations appear to be independent of one another. But this apparent independence disappears on closer study. The most striking evidence of connection between the molecular proportions exists in the case of the two oxides of iron; the ferrous and ferric oxides are noticeably inversely proportional to each other, an increase

of ferrous oxide being accompanied by a decrease of ferric oxide. The total amount of iron varies irregularly, decreasing from the basic to the acidic end of the series. While each of the iron oxides is quite independent of the magnesia, it is found upon reducing all the iron to the ferrous state that there is the greatest accord between the iron and magnesia, both varying in like directions and to nearly the same extent. The magnesia drops rapidly at first, and is very erratic in the more siliceous end of the series, where it becomes very low.

The most regular variation is in the lime, which decreases steadily from the basic to the acidic end of the series. It exhibits little or no connection with the other constituents. The molecular proportion of

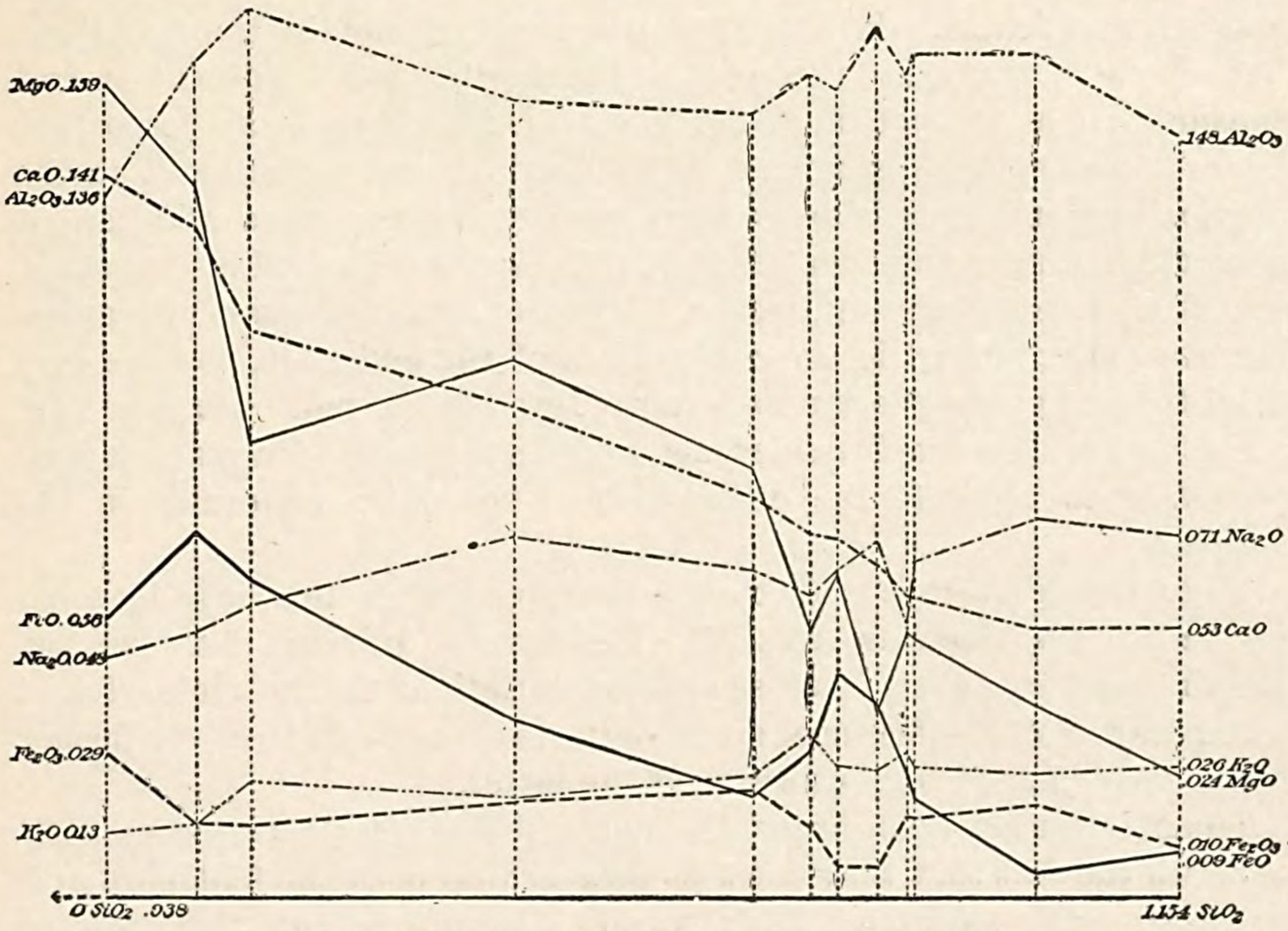


FIG. 80.—Molecular variation of the rocks at Electric Peak.

the alumina, though quite irregular between certain limits, maintains a uniformly high position, and is much greater than any one of the other constituents except silica. At the extreme basic end of the scale, however, it is equaled by both the magnesia and lime. The alkalies are most like the alumina in their variations, and remain very nearly uniform, increasing somewhat toward the acidic end of the series. The soda molecules are more than twice as numerous as those of potash, which is one of the most noticeable characteristics of the rocks of this region. In the basic end of the series the alkalies vary together in the same direction, while in the more siliceous end they vary in opposite directions. There is a marked accordance between the soda and alumina, both varying in the same direction, with one exception, though not to the same extent. There is a more strongly marked discordance

between the alumina and magnesia, which, with one exception, vary in opposite directions.

These irregular variations take place not only among allied varieties of rocks, but even in different parts of one and the same rock body. They correspond to variations in the proportions of the essential minerals. Since the essential minerals of this group of rocks are, the feldspars, pyroxenes, amphiboles, mica, quartz, and magnetite, one or more of which may be absent from a particular form of the rock; and since there is a number of complex molecules into which any one of these oxide molecules enters, it is evident that the variations among the oxide molecules must be mutually dependent. Thus, while most of the alumina enters into the feldspars, a portion of it enters into the ferromagnesian silicates. The alkalies are mostly found in the feldspars, but a little of the soda takes part in the augites and hornblendes, and considerable of the potash in the biotites. The lime is an important factor in both these groups of minerals; it is most abundant in the plagioclases and diminishes as the feldspars become more alkaline; it abounds in augite and to a less extent in hornblende, and is almost absent from hypersthene and biotite. The iron and magnesian molecules, however, have no part in the composition of the feldspars, and are confined to the ferromagnesian minerals. Besides the more complex minerals there are the simple oxides, magnetite and quartz. They act as compensators to regulate the exhaustion of the oxide molecules in the magma.

These considerations render more comprehensible the variations expressed in the diagram, Fig. 80. The inverse relation between the alumina and magnesia corresponds to variations in the molecules of feldspars and of the ferromagnesian silicates; an increase of the former being accompanied by a decrease of the latter.

The independently uniform variation in the lime molecules is consistent with the fact that they enter so largely into both the feldspars and ferromagnesian silicates. Their steady diminution from the basic to the acidic end of the series is in accord with the decrease in the amount of augite and hornblende, and the increase in the alkali feldspars, which is indicated by the increase of soda and potash molecules.

The reciprocal relation between the ferrous and ferric oxides indicates the variable oxidation of preexisting molecules, which were probably ferrous oxide; and, since the hornblende and biotite are the silicate minerals carrying the greatest percentage of ferric iron, the variation in the oxidation of the iron is naturally in accord very largely with the amount of these minerals in the rock. This is most significant from its bearing on the question of the development of hornblende and biotite in the coarser grained forms of these rocks, and from its possible connection with the work of mineralizing agents.

If we were acquainted with the exact chemical composition of each of the essential minerals in these rocks, we could obtain a more precise

notion of the interdependence of the component molecules of the magma, since we know the order in which these minerals began to crystallize in the granular rocks. But the essential minerals in the diorites are so intimately intergrown that it would be an extremely difficult, if not an impossible, matter to separate them mechanically for chemical analysis. It is possible, however, to arrive at some general conclusions by considering the approximate composition of the minerals, which may be derived from the analyses of similar occurrences.

Since the essential minerals of the diorites are magnetite, hypersthene, augite, hornblende, biotite, labradorite, oligoclase, orthoclase, and quartz, they may be placed in two series; one, including those bearing iron and magnesia; the other, being free from both. The terms labradorite and oligoclase include all the varieties of the lime-soda feldspars within the limits of these species in the Tschermak sense.

When arranged in the order in which they began to crystallize, the first series becomes magnetite, hypersthene, augite, hornblende, and biotite; the second series is labradorite, oligoclase, orthoclase and quartz. Assuming the chemical composition of these minerals to be within the limits of similar varieties in other localities, which is of course only a rough approximation, and comparing their molecular proportions, we obtain the data presented in Table XI, very small quantities of different oxides having been omitted.

TABLE XI.—*Molecular proportions in the essential minerals of the diorite.*

	Molecular proportions.							
	SiO_2	Fe_2O_3	FeO	MgO	CaO	Al_2O_3	Na_2O	K_2O
Magnetite	.....	43	43	.....	.....	.....	.....	.....
Hypersthene	86–83	.....	29	52	.....	.....	.....	.....
Augite	83–78	(*)	7–14	30–37	32–39	3–6	.....	.....
Hornblende	78–66	3–6	9–15	32–37	16–21	10–13	.....	(*)
Biotite	66–58	3–12	(*)	22–60	.....	10–18	(*)	7–10
Labradorite	88	.....	.....	.....	21	31	7	.....
Oligoclase	103	.....	.....	.....	9	23	13	(*)
Orthoclase	106	.....	.....	.....	.....	17	(†)	18
Quartz	166	.....	.....	.....	.....	.....	.....	.....
Magnetite	.....	43	43	.....	.....	.....	.....	.....
Hypersthene	86–83	.....	29	52	.....	.....	.....	.....
Augite	83–78	(*)	7–14	30–37	32–39	3–6	.....	.....
Labradorite	88	.....	.....	.....	21	31	7	.....
Hornblende	78–66	3–6	9–15	32–37	16–21	10–13	.....	(*)
Biotite	66–58	3–12	(*)	22–60	.....	10–18	(*)	7–10
Oligoclase	103	.....	.....	.....	9	23	13	.....
Orthoclase	106	.....	.....	.....	.....	17	(†)	18
Quartz	166	.....	.....	.....	.....	.....	.....	.....

* Occasionally in small amounts. † Variable, often in considerable amounts

It will be seen from this table that the order of crystallization of the ferromagnesian silicates is according to a decreasing percentage of silica; while for the feldspars and quartz it is according to an increasing percentage of silica. That is, in the first series the most siliceous mineral crystallizes first, while in the second series the most basic crystallizes first. In the third part of the table, where the order of crystalli-

zation is given for all the essential minerals, it is seen that the silica percentage of the minerals falls and rises twice, the last minerals to crystallize being much more siliceous than the first.

The first essential mineral is iron oxide with no silica, and the last is silica combined with no other elements.

In the ferromagnesian silicates the ferrous iron decreases in quantity and the ferric iron increases, while the total amount of iron at first decreases and then increases. The magnesia decreases a little, and sometimes increases in biotite. The lime, which belongs to only two of these minerals, decreases. The alumina increases steadily. The alkalies appear in the last of the series, and only in small amount. except the potash in the biotite, which is considerable.

In the second series of minerals the variations are more regular. The alumina and lime decrease uniformly, and the alkalies increase; soda appearing before the potash.

It is to be remembered that the crystallization of these minerals in the diorite is largely synchronous for all of them; and that they simply started to crystallize in the order given. The crystallization of those near together in the series took place at one and the same time; and only the minerals at the extremes of the series may have formed at distinctly different times. The earliest minerals probably ceased to grow before the orthoclase and quartz commenced to crystallize.

In the case of the diorite at Electric Peak, then, the crystallization of the magma commenced with the separation of iron oxide alone, followed by a silicate of ferrous oxide and magnesia, with little or no lime and alumina. Then followed more complex compounds of iron oxides, magnesia, lime, alumina and alkalies. The more simple feldspar compounds began to crystallize early in the series and continued to the end, after the ferromagnesian molecules had separated from the magma, the crystallization being closed by silica alone, the least complex compound.

SEPULCHRE MOUNTAIN.

GEOLOGICAL DESCRIPTION.

East of Electric Peak, across the deeply cut valley of Reese Creek, lies Sepulchre Mountain, so called from a mass of breccia on one of its high northwest spurs, which resembles a sarcophagus. The mountain rises to a height of 9,600 feet, and stands isolated from the surrounding peaks, from which it is separated by geological faults and also by deep drainage channels. It is composed of volcanic breccias and massive lavas that form a body of rock 3,000 feet thick, resting on Cretaceous and older strata.

The southern and southwestern slopes of the mountain are rounded from the action of the ice which has passed over the mountain from the Gallatin range. They are mostly covered with grass and sage brush, and present comparatively few rock exposures. This is also the character of the hills and ridges southwest of the mountain, which lie east of the fault at the base of Electric Peak, and form part of the geological body of Sepulchre Mountain.

The north and east faces of the mountain are precipitous and rocky, and afford excellent sections of the volcanic mass. The long northwestern spur is also rugged, and exposes the geological structure of this part of the mountain. This difference of surface character is shown by the illustration, Pl. LII, from a photograph of the north and west sides of the mountain.

The breccias exhibit little or no evidence of bedding, and are associated with flows of lava, the whole having a distinctly volcanic character. The western portion of the breccia is traversed by numerous dikes of andesite and dacite, which trend for the most part in a north and northeast direction from the vicinity of Cache Lake. A few trend east. The distribution and location of these later intrusions are shown on the map, Pl. LIII, in a general way. It is probable that there are a number of dikes cutting one another in the southwestern portion, rather than a few broad bodies, as represented on the map; the data were not sufficient to locate the different bodies, and the map has been drawn so as to represent what seems to have been the order and position of the eruptions.

In the northwestern spur of Sepulchre Mountain the dikes are well marked, and stand out prominently from the surrounding breccia. They are from 5 to 25 feet wide, and are not perfectly straight, but maintain a generally uniform direction and can be traced by the eye for some distance. Long after the eruption of these dike rocks, when the region had been faulted and erosion had removed a great part of the rocks, and had cut the valley of Glen Creek, a flow of rhyolite flooded the

country and filled this valley, covering the south and west base of Sepulchre Mountain to an altitude of about 8,100 feet. The rhyolite has been almost entirely removed, but remnants of the sheet are found in numerous places. This closed the series of volcanic events, as they are recorded in this vicinity, though in other parts of the region the rhyolite was followed by eruptions of basalt.

THE VOLCANIC ROCKS AT SEPULCHRE MOUNTAIN.

The volcanic rocks composing Sepulchre Mountain consist of andesitic breccias and tuffs with lava-flows of the same andesites, besides dikes of andesite and dacite. By far the greater part of the material is tuff breccia, which is easily separable into an older and a newer, or a lower and an upper breccia.

THE LOWER BRECCIA.

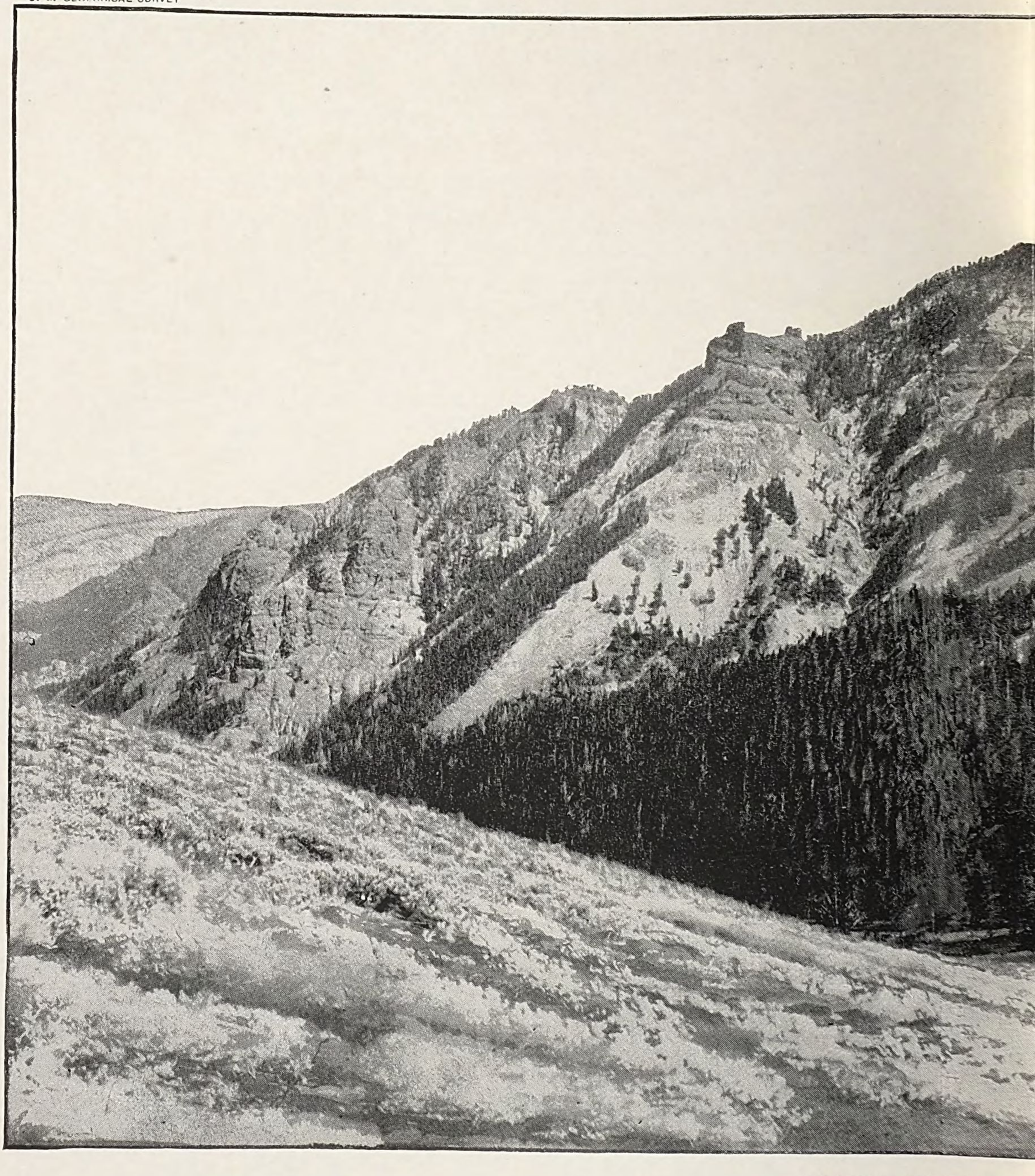
The *lower breccia*, which is about 500 feet thick, is light colored and is characterized by phenocrysts of biotite and hornblende. It carries a great amount of fragments of Archean schists which are not found in the overlying dark colored breccias. The lower breccia passes into tuff in places, containing fragments of carbonized wood; and at the extreme end of the northwest spur it is distinctly bedded with bowlders of foreign rocks scattered through layers of fine grained material. In places the upper portion of this bottom breccia is green and partly altered, as though it had been weathered before the upper breccia was deposited on it. In the northwestern spur of the mountain the upper breccia is distinctly seen to rest on an uneven surface of the lighter colored bottom breccia.

It is probable that the bottom breccia was thrown from some neighboring Archean area, and is considerably older than the overlying, basic breccia. This relation between a bottom breccia of hornblende-mica-andesite carrying Archean fragments, and overlying, basic breccias is found to exist in other places in this region.

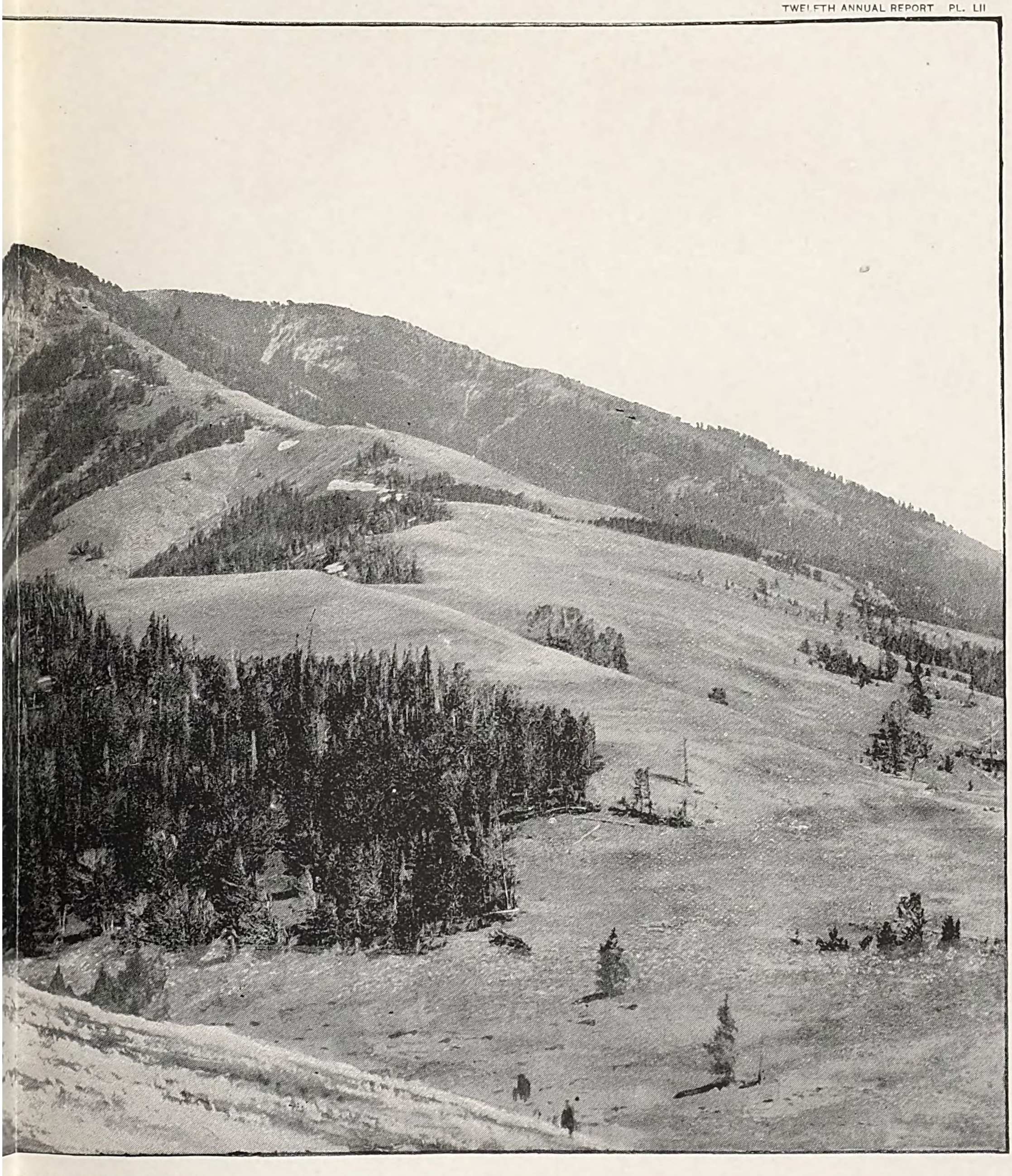
An examination of the various specimens of this older breccia shows that it varies in mineral composition as well as in color and microscopical habit. It is mostly light colored, gray, white, and red. In places it is dark colored. Some varieties carry abundant large phenocrysts, others contain a multitude of small ones. Though the great bulk of it is characterized by porphyritical biotite, hornblende and plagioclase, some portions are poor in biotite, and are hornblende-andesite, while other parts approach dacite in composition, having biotite and quartz phenocrysts with those of plagioclase. The groundmass of the different fragments making up this breccia varies from glassy and microlitic to microcrystalline.

Associated with the bottom breccia at the northeast base of Sepulchre Mountain is a vesicular basalt with porphyritical augites and decomposed olivines. It is of small extent, is amygdaloidal, with quartz, agate, and calcite. Its exact relation to the breccia was not discovered

U. S. GEOLOGICAL SURVEY



SEPULCHRE MOUNTAIN, FR



FROM ITS NORTHWEST SPUR.

but it appears to be an older basalt, more intimately connected with the bottom breccia than with the upper breccia. It does not resemble the younger basalts on the north side of the Yellowstone River opposite Sepulchre Mountain.

THE UPPER BRECCIA.

The *upper breccia*, which lies upon the one just described, is dark colored at its base, where it consists almost wholly of pyroxene-andesite with little or no hornblende. Many of the fragments are finely vesicular and basaltic in appearance, without macroscopic phenocrysts. At the south base of the mountain this breccia is accompanied by vesicular flows of pyroxene-andesite, with large porphyritical pyroxenes and feldspars. Intimately connected with this breccia is that of hornblende-pyroxene-andesite, which forms the uppermost portion of the mountain. They appear to grade into one another by an increase in the amount of hornblende. This later breccia is also accompanied by vesicular flows of the same kind of andesite. It is mostly lighter colored, though some of it is quite dark, with prominent hornblendes, and has an andesitic habit and not a basaltic one. There is no evidence of a geological break between the lower and upper portion of the upper breccia, which may be considered as a continuous geological body, made up of fragments and flows of andesite, which have been ejected from a common source during a prolonged series of eruptions.

The andesitic material composing it varies in mineral composition and outward appearance between certain limits. This variation will be described in detail.

TABLE XII.—*Mineral variation in the uppper breccias of Sepulchre Mountain.*

Mineral groups.	Specimen number.	Phenocrysts other than feldspar.			
		Pyroxene.	Hornblende.	Biotite.	Quartz.
B_1	1	much	.....	.....	.....
	2	much	.....	.....	.....
	3	much	.....	.....	.....
	4	much	.....	.....	.....
	5	much	.....	.....	.....
	6	much	.....	.....	.....
	7	much	.....	.....	.....
	8	much	.....	.....	.....
B_2	9	much	little	.....	.....
	10	much	little	.....	.....
	11	much	little	.....	.....
	12	much	little	little	.....
	13	much	little	.....	.....
B_3	14	much	some	.....	.....
	15	much	some	.....	.....
	16	much	some	.....	.....
	17	much	some	.....	.....
	18	much	much	.....	.....
	19	much	much	.....	.....
	20	much	much	.....	.....
	21	much	much	.....	.....
B_4	22	much	much	.....	.....
	23	much	much	.....	.....
	24	much	much	.....	.....
	25	much	much	.....	.....
	26	much	much	.....	.....
	27	much	much	.....	.....
B_5	28	some	much	.....	.....
	29	some	much	.....	.....
	30	some	much	.....	.....
	31	some	much	.....	.....
	32	some	much	little	.....

Thirty-two thin sections have been made from the upper breccia, which upon investigation resolve themselves into a series of glassy andesites, some of which carry hypersthene, augite, and plagioclase phenocrysts, and others hypersthene, augite, hornblende, and plagioclase. They may be arranged, as in Table XII, according to the relative abundance of these minerals.

The first two specimens are very basaltic in appearance, with small phenocrysts. They carry a few decomposed crystals, which were probably olivine, but have the microstructure of the associated andesites.

The varieties without hornblende, B_1—that is, the pyroxene-andesites—have a groundmass of globulitic brown glass filled with microlites of feldspar, pyroxene, and magnetite grains. The shade of brown varies from very dark to light, and the size and abundance of the microlites also varies. The feldspar microlites are plagioclase with rather low extinction angles.

The *pyroxene* always includes hypersthene and augite. They have very much the same general appearance and habit, both occurring in some instances in large crystals, and in others in small ones. In the same rock section they differ as to the character of their crystal outline. Some individuals are bounded by crystal planes, especially in the prism zone, while others are rounded, particularly at the ends of the crystals. Some have rough surfaces, with multitudes of irregularly shaped tongues of glass penetrating the surface of the crystal. This does not appear to be the result of a corrosion of the crystal, but of a rapid crystallization of the mineral at the end of its growth, when the surrounding glassy magma was becoming filled with microlites, and was crystallizing from more numerous centers, for there are instances where larger depressions in the surface of the pyroxene crystals can be seen to have been occasioned by the presence of small crystals of feldspar, which must have hindered the growth of the pyroxene. They have numerous inclusions of glass, with gas bubbles, which are irregularly scattered through the minerals in most cases, but are occasionally arranged zonally; besides which are grains of magnetite and a few small crystals of apatite.

The hypersthene is pleochroic, and is green parallel to c, yellow parallel to a, and light red parallel to b. In most of the thin sections it is light colored, but in one instance there is a large individual with very strong colors and pleochroism, which carries brown inclusions in the shape of thin plates arranged in lines at right angles to the vertical axis of the crystal. These inclusions resemble those characteristic of many hypersthenes in coarse grained rocks. In this instance the hypersthene crystal occurs in a glassy, vesicular rock, and the inclusions do not appear to have resulted from an alteration of the mineral subsequent to the solidification of the rock, but to have been primary inclusions of some foreign substance. The lighter colored hypersthenes do not carry such inclusions. The color frequently varies in concentric zones, the center being light in some cases and dark in others.

In some forms of the rock the hypersthene and augite have narrow reddish brown borders which are in part opaque. This border, though not so strongly marked as the black margin to many hornblendes, appears to be of similar origin and to be due to an action of the magma on the crystals before the final consolidation of the rock. It affects the pyroxene microlites in the groundmass as well as the phenocrysts.

The color of the augite is light green without pleochroism in thin sections; and is easily confounded with the sections of hypersthene which exhibit little pleochroism. Its optical characteristics are the same as those of the augite in the diorites already described; in fact, the pyroxenes of both rocks are alike optically, and have the same distinctions with respect to cleavage, which is more perfect in the augites than in the hypersthenes.

Instances of the complete inclosure of one of the pyroxenes by the other, or of their intergrowth, are rare. In the few cases observed small hypersthenes are surrounded by augite, indicating the earlier crystallization of the hypersthene. But the occasional intergrowths of the two, and the partial inclosures of adjacent individuals in groups, proves that the crystallization of most of the hypersthene and augite phenocrysts was contemporaneous. When decomposition has attacked the rock hypersthene yields before the augite, and is converted into a green fibrous mineral, probably bastite.

The *feldspar* phenocrysts are all plagioclase, which from their optical characters appear to be labradorite. They are small in most forms of the rock, but larger and more abundant in others. They are rectangular in long and short sections, a few are broad and polygonally outlined. The sections are mostly straight edged, some are rounded at the corners, and others are rough like the pyroxene crystals. The rough projections of the feldspars have crystal faces and appear to be due to an irregular checking of their crystallization. They exhibit the characteristic polysynthetic twinning of labradorite and are beautifully zonal. But the zones do not differ much in optical orientation, the extinction being quite uniform throughout each individual.

Glass inclusions are frequent in the feldspars; in some of the larger crystals the central portion is crowded with inclusions of the brown glass containing the same microlites as the surrounding groundmass. These inclusions are usually in rectangular negative crystal cavities. Many of the smaller feldspars are almost free from them. There are occasionally grains of magnetite and pyroxene.

In most cases the feldspar and pyroxene phenocrysts are separated by the groundmass of the rock. But when they occur in juxtaposition it is evident that the feldspar is a younger crystallization which started after the pyroxene had commenced to crystallize, but before it had finished, for the feldspar interferes with the perfect development of the pyroxene.

Magnetite occurs in phenocrysts associated with the pyroxene and also isolated in the groundmass. It is in definite crystals and in irregular grains.

There are five representatives of the pyroxene-andesites which carry a few crystals of hornblende, B_2, and constitute transitional varieties between these rocks and the hornblende-pyroxene-andesites. They exhibit the same characters as the andesites just described.

The *hornblende* is in small irregular crystals, some being rounded and others in angular shapes. It is reddish brown and brownish green, with strong pleochroism. Many of the individuals, especially the rounded ones, have a narrow border of magnetite or one of small crystals of pyroxene, feldspar, and magnetite. There are all gradations, from rounded hornblendes with opaque borders to small angular pieces of hornblende surrounded by comparatively large crystals of pyroxene, feldspar, and some magnetite, which form a group of interlocked crystals in the glassy groundmass. The angular outline of the hornblende and its penetration between the crystals of feldspar and pyroxene would militate against the supposition that the hornblende is a remnant of a previous crystal that had been partially resorbed in the groundmass, were it not for the occurrence in one thin section of a group of different crystals with a hexagonal outline, corresponding to the cross section of the hornblende remnants contained in it which are properly oriented for such a section. The greater part of the group consists of feldspar and pyroxene with some magnetite. It is not to be supposed that these minerals crystallized out of the melted hornblende substance without interchange of material from the surrounding magma. The larger groups in the same rock section exhibit no definite outward form, but are bounded by the outlines of the outer crystals, so that we may conclude that the process of resorption of the hornblende phenocrysts was in some cases accompanied by the immediate formation of grains of magnetite and the absorption of the other chemical constituents by the magma; while in other cases the melted hornblende recrystallized in situ as pyroxene and magnetite. But in the instances just mentioned the partial resorption of the hornblende was followed by a greater tendency toward crystallization in the magma immediately surrounding the melted hornblende, which led to the development of a group of all the minerals then capable of forming. These minerals are the same in size and character as the small crystals scattered through the glassy groundmass.

In rock section No. 12 several small individuals of biotite occur with the same kinds of borders as those surrounding the hornblende. This thin section and one other, No. 32, are the only ones carrying biotite. It is in very small amounts in each case.

The remaining thin sections may be classed as hornblende-pyroxene-andesites, in which the proportions of hornblende and pyroxene vary. In the first four, B_3, the pyroxene is in excess of the hornblende. In

the following ten, B_4, they are about equal and in the last five, B_5, the hornblende is in excess. The varieties thus form a series from those without hornblende to others with much hornblende and very little pyroxene.

In these andesites the microscopical character of the pyroxenes is the same as in those first described, except that they are in better shaped crystals, seldom rounded or with dark borders. The hypersthene is mostly light colored in thin section, but in several rock sections some of the individuals are strongly colored at the center, while others are more strongly colored at the margin.

The *hornblende* differs throughout these sections in color and in the extent to which it has been resorbed. In some cases it shows no sign of resorption. The form of the crystals when perfect is derived from the unit prism and clinopinacoid and the usual terminations. In many instances the crystal faces are poorly preserved and only the general characteristic form remains, especially in cross sections.

The color is intensely red in some varieties of the rock, in others it is reddish brown, chestnut brown, greenish brown, and also brownish green, with the corresponding pleochroism. This difference of color bears no relation to the presence or absence of opaque border nor to the amount of resorption exhibited by the hornblende. It does not appear to be due to secondary alteration of the hornblendes, since they all occur in perfectly fresh glassy rocks, and the color is generally uniform for all the hornblende in one rock section, when the rock is not a tuff.

The character of the border when present varies for different individuals of hornblende in one rock section. Around some it is a narrow margin of magnetic grains, while in a few instances it is a heavy opaque border. Other hornblendes in the same section are surrounded by crystals of pyroxene, plagioclase, and magnetite. In many sections, however, all the hornblendes have been affected to the same extent and have a narrow opaque border, while in others there are no borders at all.

It does not seem possible to connect the character or degree of the resorption with any definite degree of crystallization of the groundmass of the rocks. And, as just stated, different phases of resorption and of borders occur in one and the same rock section. It is often noticed that the center as well as the margin of the hornblende crystal has become an aggregate of pyroxenes and feldspars, and that very little of the hornblende substance remains. But it is also observed that many of the hornblendes which show no evidence of resorption have large and irregularly shaped inclusions and "bays" of the groundmass in them. So that it is probable that many of the cases of apparent extensive resorption or corrosion may be crystals which originally contained large bays of groundmass. Inclusions of glass are not very abundant, except in certain individuals.

There are numerous instances in which the hornblende incloses small pyroxenes and plagioclases, as well as magnetites, and others in which hornblendes and plagioclases have crystallized beside each other and have mutually interfered, proving that their growth was contemporaneous in part. As there are two or more generations of plagioclase and pyroxene, it is natural that the hornblende appears to be contemporaneous with the earlier feldspars and pyroxenes, and older than the later generations.

The *feldspars* are all plagioclase, but appear to belong to different species. They are in rather small crystals in most of the rock sections. The larger ones are generally labradorite, and many of the small ones are the same, but in a number of the sections the extinction angles indicate andesine or oligoclase. They are mostly rectangular with perfect crystallographic outline, some are tabular and polygonal, and in this position they exhibit the most striking zonal structure, which is almost universally present. The twinning is that characteristic of andesitic plagioclases. Glass inclusions are of frequent occurrence. In some cases the feldspar contains a great amount of glass which almost equals the bulk of the feldspar substance. Occasionally the feldspar has an irregular form and an indented outline, made by the projection of crystal points, the margin of the individual having a different optical orientation from the central portion, and appearing to be formed of more alkaline plagioclase. These are not very common.

The groundmass of these andesites is the same as that of the pyroxene andesites in some cases, and is composed of globulitic brown glass with microlites of pyroxene, feldspar and magnetite. But in most of the sections it consists of colorless glass crowded with small microlites of the same minerals. It carries microscopic crystals of these minerals which are porphyritical with respect to the groundmass when seen with a microscope, but which in turn form part of the groundmass which carries the macroscopic phenocrysts.

THE DIKE ROCKS.

The dike rocks of Sepulchre Mountain, as already mentioned, consist of a series of andesites and dacites, the earliest of which resemble the pyroxene-andesites and hornblende-andesites of the breccias. They vary in mineral composition as indicated by the porphyritical crystals of all sizes that are scattered through the groundmass, and range from rocks with phenocrysts of hypersthene, augite and plagioclase, to those with phenocrysts of quartz, biotite, hornblende and plagioclase. This variation is shown in the accompanying table (Table XIII), in which the 103 thin sections of these dike rocks are arranged according to the porphyritical minerals contained in them.

While the greater number of pyroxene-andesites and hornblende-pyroxene-andesites carry no biotite, there is a small amount of it in some of the latter varieties. In one instance biotite, hornblende, and pyroxene occur together in considerable amounts.

TABLE XIII.—*Mineralogical variations in the dike rocks of Sepulchre Mountain.*

Mineral group.	Specimen number.	Phenocrysts other than feldspar.				Mineral group.	Specimen number.	Phenocrysts other then feldspar.			
		Pyroxene.	Hornblende.	Biotite.	Quartz.			Pyroxene.	Hornblende.	Biotite.	Quartz.
D_1	33	much	.....	.....	.....	D_7	85	.....	much	some	.....
	34	much	.....	.....	.....		86	.....	much	some	.....
	35	much	.....	.....	.....		87	.....	much	some	.....
	36	much	.....	.....	.....		88	.....	much	some	.....
	37	much	.....	.....	.....		89	.....	much	some	.....
	38	much	(?)	.....	.....		90	.....	much	much	.....
D_2	39	much	little	.....	.....		91	little	much	much	.....
	40	much	little	.....	.....		92	.....	much	much	.....
	41	much	little	.....	.....		93	.....	much	much	.....
	42	much	little	.....	.....		94	little	much	much	.....
D_3	43	much	some	.....	.....		95	.....	much	much	.....
	44	much	some	.....	.....		96	.....	much	much	.....
	45	much	much	.....	.....	D_8	97	.....	much	much	.....
	47	much	much	.....	.....		98	.....	much	much	.....
	48	much	much	.....	.....		99	.....	much	much	.....
	51	much	much	trace	.....		100	.....	much	much	.....
	52	much	much	little	.....		101	.....	much	much	.....
	46	some	much	little	.....		102	(?)	much	much	.....
	49	some	much	little	.....		103	(?)	much	much	.....
	50	some	much	little	.....	D_9	104	.....	some	much	.....
D_4	54	little	much	.....	.....		105	.....	some	much	.....
	55	little	much	.....	.....	D_{10}	108	much	much	much	little
	56	little	much	.....	.....		114	little	much	much	little
	57	little	much	.....	.....		115	little	much	much	little
	58	little	much	.....	.....		106	.....	much	much	little
	60	little	much	.....	.....		107	.....	much	much	little
	63	little	much	.....	.....		109	.....	much	much	little
	65	little	much	.....	.....		110	.....	little	much	little
	66	little	much	(?)	.....		111	.....	much	much	little
	61	trace	much	.....	.....		112	.....	much	much	little
	64	trace	much	.....	.....		113	.....	much	much	little
	53	little	much	little	.....	D_{11}	116	.....	much	much	much
	59	little	much	little	.....		117	.....	much	much	much
	62	trace	much	little	.....		118	.....	much	much	much
	67	little	much	little	.....		119	.....	much	much	much
D_5	68	.....	much	.....	.....		121	.....	much	much	much
	69	.....	much	.....	.....		122	.....	much	much	much
	70	.....	much	.....	.....		123	.....	much	much	much
	71	.....	much	.....	.....		126	.....	much	much	much
	72	.....	much	.....	.....		127	.....	much	much	much
	73	.....	much	.....	.....		120	.....	some	much	much
	74	.....	much	.....	.....		124	.....	some	much	much
	75	.....	much	.....	.....		125	.....	some	much	much
	76	.....	much	.....	.....		128	.....	some	much	much
	77	.....	much	.....	.....		129	.....	some	much	much
	78	.....	much	.....	.....		130	.....	some	much	much
	79	.....	much	.....	.....	D_{12}	131	.....	little	much	much
	80	.....	much	.....	.....		132	.....	little	much	much
	81	.....	much	.....	.....		133	.....	little	much	much
	82	.....	much	.....	.....		134	.....	little	much	much
D_6	83	.....	much	little	.....		135	.....	little	much	much
	84	.....	much	little	.....						

There is a number of hornblende-andesites with neither pyroxene nor biotite, and others with a small amount of both. In most of the hornblende-mica-andesites there are no porphyritical pyroxenes; they occur in a few varieties only and in small amounts, and are equally rare in the dacites.

The greatest amount of porphyritical quartz is generally accompanied by considerable biotite and less hornblende.

Plagioclase feldspars are present in all the varieties of these rocks, but vary in composition from labradorite in the basic andesites to oligoclase or andesine in the dacites.

As to the microscopical characters of the essential minerals it may be said that they are like those already described for the essential minerals in the andesites which form the breccias.

The *pyroxenes* are the same, and consist of hypersthene and augite in all cases where they are fresh. In many instances a part of the pyroxene is entirely altered and part is fresh, and is augite, the hypersthene having been completely decomposed. They have the same color and pleochroism and crystal form as those in the andesites just described, and need no further comment.

The *hornblende* in some of the pyroxene-andesites is represented simply by paramorphs, which consist of grains of magnetite and pyroxene with the outward form of hornblende crystals; in others it is in small individuals, with a broad or narrow black border, occasionally with no border. In the hornblende-pyroxene-andesites the hornblende has a black border in some instances, but in the majority of cases it is entirely free from any border; the same is true of it in the hornblende-andesites. In the more acid andesites and dacites the hornblende exhibits no signs of black border.

In many instances where the crystal form is well developed both the orthopinacoid and clinopinacoid is present besides the unit prism faces, which is characteristic of the hornblende in the diorites of Electric Peak.

The color of the hornblende varies somewhat from brown and greenish brown to brownish green and green, with the usual pleochroism. It is brown and greenish brown in most of the pyroxene- and hornblende-andesites, but is very generally green and brownish green in the hornblende-mica-andesites and dacites. Its color is like that of the hornblendes in the porphyrites and diorites of Electric Peak.

Many of the hornblendes carry glass inclusions, and some have large bays and irregularly shaped inclusions of groundmass. They also inclose grains of magnetite and apatite, and occasionally are intergrown with pyroxene in such a manner that the two appear to have crystallized at the same time.

In some of the dacites the hornblende is entirely decomposed, while the biotite is still intact.

The *biotite* is chestnut brown, in thin section, with the ordinary absorption. The optic angle is very small and the mineral behaves like a uniaxial one. Its crystal form is simple and the individuals are generally quite thick. It is unaltered in almost all the rock sections, and carries a variable amount of inclusions of magnetite and apatite, with occasional zircon. In one instance it completely incloses a small crystal of plagioclase.

The *feldspars* are all plagioclase, and exhibit the characteristic polysynthetic twinning. In the more basic andesites they are mostly very small individuals, with rectangular sections and high extinction angles, indicating labradorite. They are usually very abundant. In some instances they are fewer in number, and do not exhibit high extinction angles or high double refraction, and appear to be oligoclase.

In the more acid andesites and dacites the plagioclases are larger and have more crystal faces, the sections being more polygonal and broader. The extinction angles are lower, and there seems to be sev-

eral kinds of plagioclases among the phenocrysts; some are sharply rectangular with numerous twin lamellæ, and extinction angles indicating labradorite, while the majority of the individuals are not rectangular, have fewer lamellæ and lower extinction angles, and exhibit very marked zonal structure. They appear to be oligoclase; they all carry more or less glass inclusions, which are very abundant in some individuals and in some rock sections, and are quite scarce in others. The different specimens of the rocks vary greatly in the amount of inclusions in the phenocrysts. In one of the hornblende-andesites which has a brown, globulitic, glassy groundmass, many of the feldspars inclose patches and small bits of the brown glass, but one of the larger plagioclases also carries a great number of opaque needles and grains, arranged in several systems of parallel lines, which are identical with the inclusions in many of the labradorites in the diorites of Electric Peak. Besides this individual of feldspar there are several others which exhibit the same thing to a slight degree. There is another fine example of it in a glassy hornblende-andesite; the feldspar in this case carries abundant inclusions of glass as well as the clouds of microscopic needles. This is important, as it proves the primary nature of these particular inclusions, and indicates that the phenocrysts containing them crystallized under conditions similar to those attending the crystallization of the labradorites in the diorites of Electric Peak.

The *quartz* phenocrysts occur in the biotite-hornblende rocks, and vary in amount from a few microscopic individuals to very abundant macroscopic ones. Their crystal form is well marked in many cases and corresponds to the double pyramid, but other individuals in the same rock section are rounded, and some have quite an irregular outline. It seldom, if ever, happens that all the individuals of quartz in one rock section exhibit the same degree of perfection of crystal form; rounded grains and idiomorphic crystals are scattered indiscriminately through the rock. The same is true in many instances of the hornblende individuals, as already described.

The quartzes occur singly in isolated crystals, and also in groups of two or more individuals with different orientations, grown together in the same manner as those of feldspar or of the ferromagnesian silicates. Glass inclusions are found in nearly all the quartzes, but in very different amounts, some being crowded with them, while others are almost free from them. They are usually in negative crystal cavities, occasionally in rounded ones. In some cases they are accompanied by the six-rayed cracks so common in the quartzes of rhyolites. The quartzes often inclose bays of groundmass, and occasionally small crystals of hornblende, biotite, and plagioclase. These latter inclosures show that the quartzes crystallized after part, at least, of the hornblende, biotite, and plagioclase had crystallized. The inclosing quartzes are rounded at the corners. In one instance a quartz contains small fluid inclusions besides those of glass.

Magnetite, which is very abundant in the more basic rocks, and is in much smaller amounts in the dacites, needs no special description.

The *apatite* occurs in short, stout, hexagonal prisms; it is colorless, and is rare in the basic andesites, and more abundant in the more acid andesites and dacites. The same is true of the *zircon*, which is seldom observed in the basic andesites.

Small individuals of *allanite* are found in three of the dacite sections. It is dark brown, with strong absorption.

The groundmasses of these rocks, which result from the processes of final solidification of the various magmas, differ in degree of crystallization, in mineral composition, and in structure.

In the pyroxene- and hornblende-pyroxene-andesites the groundmass in many cases is glassy, with multitudes of microlites of pyroxene and plagioclase and grains of magnetite. In many others it is completely crystallized and the outline of the microlites is no longer sharply defined. In one glassy hornblende-pyroxene-andesite there is a segregation of minerals, which is interesting from the fact that the mass is not holocrystalline, but contains in the interstices between the large crystals vesicular glass with skeleton feldspars, and much fewer microlites than the glassy groundmass contains. The segregation, at first glance, resembles those holocrystalline groups of hornblende and plagioclase so common in the andesites and porphyrites. It consists of large hornblende crystals, with a few small biotites and pyroxenes inclosed in them, besides some plagioclase. But the feldspars carry many fine glass inclusions, which are also found in the hornblendes. The interstitial glass is partly colorless, partly globulitic, carrying long, slender skeleton plagioclases, with square cross sections, and a few needles of pyroxene with grains of magnetite attached. This glass is quite vesicular, while the groundmass of the rock presents a wholly different appearance. The latter is compact, and crowded with small microlites of feldspar and pyroxene and magnetite, having a typical felt-like structure. The hornblende and plagioclase of the segregation have the same characters as those of the same minerals in the surrounding rock, but they carry more glass inclusions. The crystal form of the minerals on the outside of the segregation is perfect, and the large crystals project into the surrounding groundmass of the rock. The segregation can not be the broken fragment of some foreign rock mass, but must be a local crystallization which advanced more rapidly than that of the surrounding portion of the rock, but did not result in complete crystallization. Within the interstitial glassy portion are numerous hollow cavities.

In the holocrystalline varieties of these rocks the groundmass has attained different degrees of crystallization, which may be compared with those exhibited by the intrusive rocks at Electric Peak. Separating the rocks into five groups to correspond to the preponderance of pyroxene with little hornblende; of pyroxene and hornblende; of hornblende alone, or with little pyroxene; of hornblende and mica, and of

mica, hornblende, and quartz (See Tables XII and XIII), and arranging them according to the size of grain of the groundmass, they fall into the order given in Table XIV. In this table the grades of crystallization correspond to those established for the intrusive rocks of Electric Peak, which are expressed in Table VIII, with the addition of five more divisions which embrace two finer grained degrees of holocrystalline structures and three degrees of glassiness.

TABLE XIV.—*Grades of crystallization of the eruptive rocks of Sepulchre Mountain.*

	B_1, B_2, D_1, D_2.	B_3, B_4, B_5, D_3.	D_4, D_5, D_6.	D_7, D_8, D_9.	D_{10}, D_{11}, D_{12}.
1	9, 10	28	.....	.....	.....
2	1, 2, 3, 4, 11, 12, 33, 34, 35, 39, 40	14, 18, 29	68	.....	.....
3	5, 6, 7, 8, 13, 41	15, 16, 19, 20, 21, 22, 23, 24, 25, 30, 43, 44, 45, 46	.....	.....	.....
4	.....	17, 26, 27, 31, 32	53, 69, 70, 83	85	.....
5	.....	.....	54, 71, 72	90, 91, 104	.....
6	36	47, 48, 49	55, 73, 74	86, 92, 93	106, 116, 117
7	37	.....	75, 76, 77, 84	94, 95	107, 118, 119, 120, 131
8	.....	.....	56, 57, 58, 59, 79, 80, 81, 78	87, 96, 97, 98	108, 109, 110, 111, 121, 122, 123, 124, 125, 132, 133
9	.....	.....	60, 61, 62, 63. 64	99, 100, 105	112, 126, 127
10	.....	.....	.....	.....	.....
11	.....	.....	65, 66, 82	.....	134
12	.....	50	.....	88, 89	.....
13	.....	.....	.....	.....	113, 135
14	38	51	.....	101	.....
15	.....	.....	.....	.....	.....
16	.....	.....	67	102	.....
17	.....	.....	.....	.....	.....
18	.....	.....	.....	.....	128
19	.....	.....	.....	103	114, 115, 129, 130
20	.....	52	.....	.....	.....
21	.....	.....	.....	.....	.....
22	.....	.....	.....	.....	.....
23	.....	.....	.....	.....	.....
24	.....	.....	.....	.....	.....
25	42	.....	.....	.....	.....

The microstructure of the acidic varieties is not the same as that of the basic, so that it is difficult to compare the grain of one directly with that of the other; but since the intermediate rocks possess microstructures intermediate between these extremes, it is possible to establish a kind of relationship between them, and it is admissible to place them in the same line across the table, it being understood that the correspondence is an approximation.

A glance at Table XIV shows that a great majority of the varieties are very fine grained forms that have only reached the crystallization of the few smallest grained forms of the Electric Peak rocks. A small number of them are more coarsely microcrystalline and correspond to the grain of the dike rocks at Electric Peak. A large number are finer grained than any of these rocks, or are glassy. The coarsest grained forms have been attained by the most basic varieties, but they do not represent bodies of any considerable extent. Specimen No. 42,

grade 25, comes from a small exposure with no definite limits, surrounded by much finer grained rocks. It is properly a diorite-porphyrite, and carries much biotite of final consolidation, which has not been reckoned with the phenocrysts.

The coarsest grained forms of the acid varieties, however, represent larger bodies and are more abundant in the field.

In explanation of the degrees of crystallization indicated in the table, it may be said that the first three are glassy groundmasses, the first one having fewer microlites than the second. In the third the microlites are closely crowded together. The next two represent microlitic structures in which no glass can be detected; they appear to be holocrystalline. In the sixth grade the form of the microlites is more indistinct, but the general structure is the same as before. Beyond this the different degrees indicate increasing grades of a structure which may be described in general as follows: Commencing with the lowest order, the groundmass is composed of a multitude of indistinct microlites of lath-shaped feldspars; between crossed nicols this aggregation extinguishes light in small patches, which bear no fixed relation to the position of the microlites within them. As the dimensions of the lath-shaped feldspars become larger it is observed that the patches of light and darkness arise from the cementing material between these feldspars. This cement possesses the same optical orientation for small spaces which in cross section produce the patches just alluded to. In still coarser grained forms it becomes apparent that the cementing material is quartz which has crystallized in irregularly shaped patches inclosing many smaller feldspars. The size of these feldspars and of the interstices between them is taken as the grain of the rock, and not the size of the patches of quartz. For it is observed that as the rocks become more coarsely crystalline the feldspars, which are plagioclase, increase steadily in size and each quartz patch cements fewer of them, until in still coarser grades the quartz forms allotriomorphic individuals between the plagioclases and does not surround any, so that in these varieties of rock the size of grain is judged by the dimensions of the plagioclases and the interstices of quartz. The patchy structure just described is that already mentioned on page 589 and called micropoicilitic.

In the most siliceous varieties of the rocks the microstructure is different. The smallest grained forms appear to approach a granular structure, in which, however, the feldspars exhibit a more or less rectangular shape and the quartz shows a tendency to appear in minute, poorly defined dihexahedrons. As the grain becomes larger the form of the quartz grains becomes more pronounced. They are rudely idiomorphic, with sections that are in many cases equilateral rhombs, extinguishing the light parallel to their diagonals. In the coarsest grained forms of the dacites these imperfectly idiomorphic quartzes are characteristic of the groundmass and reach a diameter of from $0{\cdot}08^{mm}$ to $0{\cdot}10^{mm}$. Their surface is indented with the ends and corners of small

plagioclases, the structure of the groundmass being hypidiomorphic. These quartzes often contain minute colorless inclusions in negative crystal cavities which have every appearance of being glass and correspond to the glass inclusions in the quartz phenocrysts of the same rocks. The partially idiomorphic quartzes in the groundmass are to a slight degree porphyritical with respect to the other constituents, but belong to the final consolidation of the magma.

GENERAL CONSIDERATION OF THE MINERAL AND CHEMICAL COMPOSITION OF THE ERUPTIVE ROCKS OF SEPULCHRE MOUNTAIN.

Mineral composition.—The mineral variations in the group of rocks forming Sepulchre Mountain are much simpler and require much less discussion than those of the intrusive rocks of Electric Peak. They have already been expressed in the Tables XIII and XIV. From these tables it is evident that the so-called transitional forms of the rocks are as numerous and as important as those forms which would be considered type rocks. It is possible to describe those varieties of andesite with augite and hypersthene and no hornblende as typical pyroxene-andesite, those varieties with nearly equal amounts of pyroxene and hornblende as typical hornblende-pyroxene-andesites, those varieties with hornblende alone as typical hornblende-andesites, and so on for typical hornblende-mica-andesites and typical dacites. And for convenience of description this may be admissible. But in the occurrence at Sepulchre Mountain such a method of description would create a false impression and would lead one to expect definite bodies of such type rocks with facies which should present the transitional variations; whereas, there are definite bodies of the so-called type rocks and equally definite bodies of the intermediate varieties which are quite as numerous. There is no particular mineralogical modification of the rocks at this place, which from its greater abundance or its special mode of occurrence renders it a type rock. On the contrary, the whole accumulation of eruptive rocks which are subsequent to the bottom breccia, with its admixture of Archean fragments, must be considered as a series of volcanic rocks that vary in mineral composition, through gradual changes from pyroxene-andesite to dacite.

Starting with those rocks which carry phenocrysts of pyroxene and plagioclase, it is observed that as the hornblende makes its appearance and increases in amount the pyroxene decreases. Biotite accompanies the hornblende in the more acidic varieties and increases in amount with the acidity of the rock. Quartz first appears in small quantities and increases with the acidity of the rock, the hornblende decreasing at the same time. To this rule there are exceptions which are indicated in the table; biotite is found to a slight extent in some of the hornblende-pyroxene-andesites and pyroxene occurs in small amounts in some of the hornblende-mica-andesites. It is, of course, understood that this relation between the essential minerals may be different for groups of andesites in other regions.

Chemical composition.—The chemical composition of the eruptive rocks of Sepulchre Mountain is shown in the accompanying table of chemical analyses:

TABLE XV.—*Chemical analyses of rocks from Sepulchre Mountain.*

Specimen number.	33	80	20	2	21	95	102	129	131
SiO_2	55.83	55.92	56.61	57.17	60.30	64.27	65.50	65.66	67.49
TiO_2	1.05	.94	.79	1.03	.76	.32	.45	1.37	.13
Al_2O_3	17.11	17.70	13.62	17.25	16.31	17.84	14.94	15.61	16.18
Fe_2O_3	4.07	3.16	5.89	2.48	4.35	3.36	1.72	2.10	1.30
FeO	3.75	4.48	2.60	4.31	1.41	1.29	2.27	2.07	1.22
MnO	none	trace	.35	none	.13	none	.20	none	.08
CaO	7.40	5.90	6.61	6.61	5.62	3.42	2.33	3.64	2.68
BaO	.....	.....	.14	.....	.15	.....	.13	.....	.....
MgO	5.05	4.34	5.48	4.83	2.39	2.00	2.97	2.46	1.34
SrO	.....	.....	trace	.....	trace	.....	trace?	.....	.....
Li_2O	none	.09	.....	trace	.....	.03	.....	.36	.....
Na_2O	2.94	4.08	3.13	3.44	3.99	3.84	5.46	3.65	4.37
K_2O	1.71	2.28	2.71	2.03	2.36	2.48	2.76	2.03	2.40
P_2O_5	.21	.18	.06	.05	.20	.16	.09	trace	.13
SO_3	trace	trace	?	trace	.10	trace	.06	.13	.....
Cl	none	none	.....	trace	.....	none	.....	.12	.....
CO$_2$	.....	.....	none	.....	none	.....	none	.....	.....
H_2O	1.28	1.42	2.27	1.20	2.50	1.32	1.37	1.07	2.69
	100.40	100.45	100.26	100.40	100.57	100.33	100.25	100.27	100.01
Less O for Cl	.....	.....	.....	.....	.....	.....	.....	.03	
								100.24	

Nos. 33, 80, 2, 95, and 129 were analyzed by Mr. J. E. Whitfield, Nos. 20, 21, and 102 were analyzed by Dr. T. M. Chatard, and No. 131 was analyzed by Mr. L. G. Eakins.

The first, No. 33, and fourth, No. 2, are analyses of pyroxene-andesites which carry no hornblende; the first is a dike near the summit of the mountain, the other is from a surface flow at its southwest base. Nos. 20 and 21 are of hornblende-pyroxene-andesites, occurring as breccia in the upper part of the mountain. No. 80 is of hornblende-andesite, which is an intruded body in the small hill northeast of Cache Lake at the head of Reese Creek. No. 95 is a hornblende-mica-andesite from the same locality, also an intrusive rock. No. 102 is the same kind of andesite from an intrusive mass at the north base of Sepulchre Mountain, and Nos. 129 and 131 are dacites from the ridge south of Cache Lake.

The range of variation in the percentage of silica is about the same as that of the rocks at Electric Peak. The character of the variations of the other oxides in these rocks is shown by the accompanying diagram, which represents the variations in the molecular proportions of the essential oxides and has been plotted in the manner already described on page 628.

A glance at this diagram shows that it has the same form as that of the group of analyses of the rocks from Electric Peak. The variations in the oxides other than silica are quite irregular for a gradual change in the silica. The alumina varies rapidly in places and retains a high position in the diagram. The alkalies gradually increase with the silica, the soda molecules being twice as numerous as those of potash and their variations being alike with one exception. Magnesia varies most widely and in striking contrast to the alumina; in each instance they

vary in opposite directions. The lime is nearly as irregular as the magnesia, both decreasing rapidly from the less siliceous to the more siliceous end of the series. The two oxides of iron are strikingly reciprocal in their variations, the significance of which has been pointed out in discussing the diagram for Electric Peak. In the group of analyses from Sepulchre Mountain the oxidation of the iron bears a noticeable relation to the presence of hornblende, biotite, and magnetite in the rocks.

From a study of these analyses it is evident that the chemical variations in this group of rocks are the same in character and extent as those in the intrusive rocks of Electric Peak. Moreover, it appears that the variations between similar varieties of andesite—such as those between different pyroxene-andesites—are as great as and in some cases

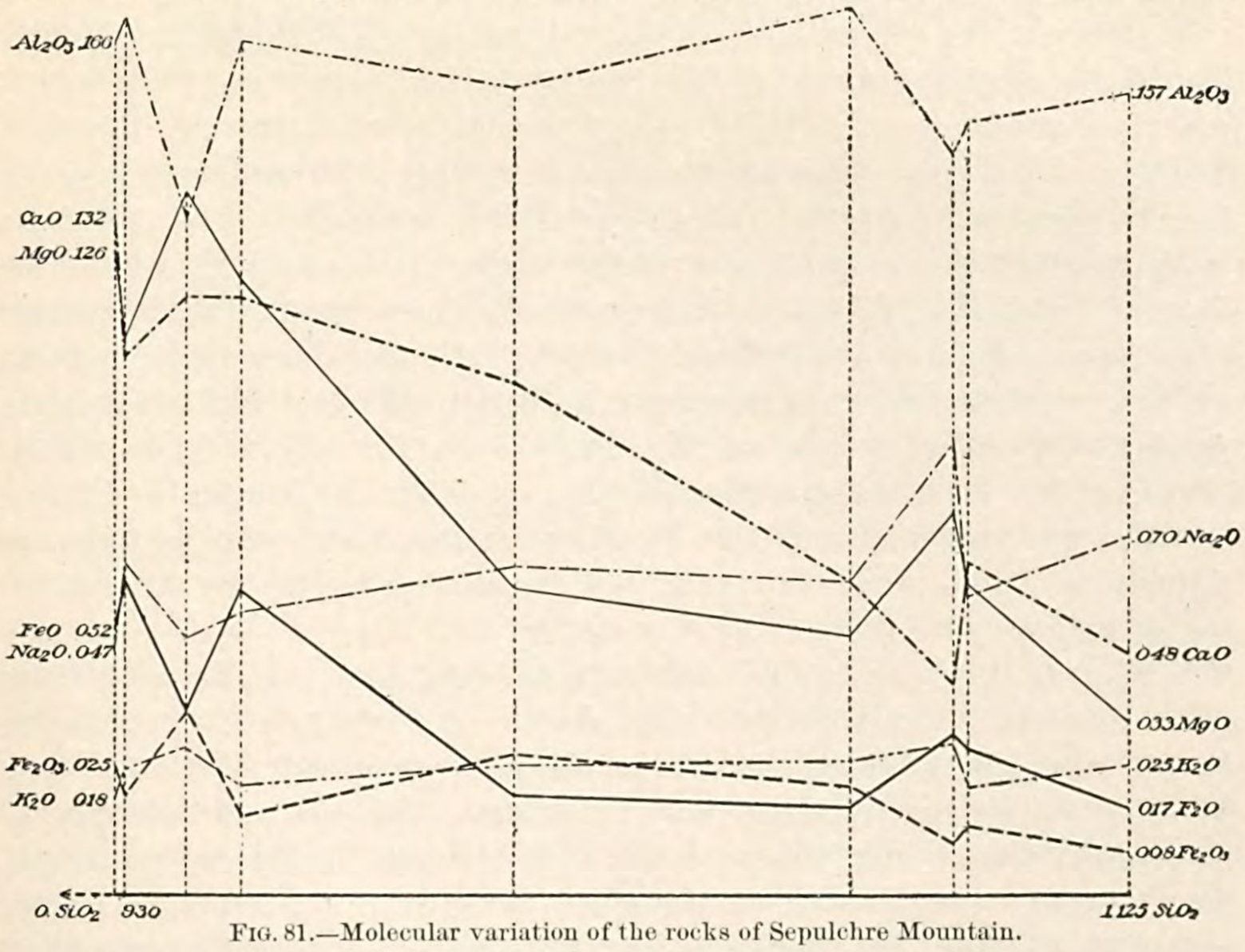


FIG. 81.—Molecular variation of the rocks of Sepulchre Mountain.

greater than the variations between varieties of andesites which are distinguished mineralogically from one another. Thus Nos. 33 and 2 are pyroxene-andesites without hornblende, Nos. 20 and 21 are hornblende-pyroxene-andesites, while No. 80 is a hornblende-andesite. It is not possible to point to any chemical character of these rocks which is distinctive of this mineral variation, with the exception of the oxidation of the iron, which, though slight, is an important one; for it undoubtedly relates to forces which did not alter the fundamental relation between the bases in the magma, but simply modified it by changing the oxidation of one of them. The last four analyses are of hornblende-mica-andesites and dacites. The chemical variations between them are as pronounced as those between the more basic members of the series, without there being the corresponding differences between the kinds of ferromagnesian silicates, so far as it can be detected microscopically.

They all carry hornblende and biotite and no pyroxene, the relative proportions of these minerals varying. The character and amount of the feldspars differ in these rocks, and so do the abundance and mode of occurrence of the quartz. In Nos. 129 and 131 quartz appears as phenocrysts; in the other rock it is confined to the groundmass.

COMPARISON OF THE ROCKS FROM THE TWO LOCALITIES.

Having described the geological structure of Electric Peak and of Sepulchre Mountain and the occurrence and character of the igneous rocks in each locality, it remains to point out the relationship of the two groups of rocks to each other, and the petrological deductions which may be drawn from their investigation.

To arrive at the relationship of the volcanic rocks of Sepulchre Mountain to the intrusive rocks of Electric Peak it is necessary to observe, in review of the facts already presented, that the latter cut through Cretaceous shales and sandstones and have imparted sufficient heat to them to metamorphose them for a great distance, indicating the passage of large quantities of molten magma through the fissures; while the lavas of Sepulchre Mountain rest on Cretaceous strata and also carry large blocks of black shale inclosed within them. They plainly show by their crushed and dragged portions that a profound fault has separated the block of Sepulchre Mountain from that of Electric Peak, dropping the former down considerably more than 4,000 feet. Consequently the volcanic rocks of Sepulchre Mountain once occupied a higher elevation than the present summit of Electric Peak and its bodies of intrusive rock.

In Electric Peak there is a system of fissures that radiates outward toward the south and southwest, as shown by the dikes of porphyrite. At the west base of Sepulchre Mountain there is a system of dikes and intruded bodies that radiates outward toward the north and northeast. These fissures antedate the great faulting just mentioned and represent the east and west halves of a system of fissures trending from north and south around to northeast and southwest which crossed one another at the point where the broadest body of intruded rock is now found. The axis of this system appears to have been inclined toward the east, that is, to have dipped toward the west, and was cut across by the great fault which dropped Sepulchre Mountain.

The igneous rocks that broke through the strata of Electric Peak consist of a series of porphyrites, occurring in sheets between the strata, and another series of diorites and porphyrites that were erupted through the vertical fissures just alluded to. The central fissure or fissures became the conduit through which the molten magmas followed one another at successive intervals of time. In the outlying narrow fissures the magmas solidified as dikes of porphyrite, while within the heated conduit they consolidated into coarse grained diorites of various kinds. The magmas of this series of eruptions became more and more siliceous. Their succession is indicated in the accompanying table.

TABLE XVI.—*Order of eruption of the rocks at Electric Peak and Sepulchre Mountain.*

Succession of eruptions at Electric Peak.	Succession of eruptions at Sepulchre Mountain.
A. Intrusion of sheets of **porphyrite** from the southwest.	A. Extravasation of **andesitic breccia** from some Archean area.
B. Intrusion of **dike- and stock-rocks** in the following order:	B. Eruption of **andesitic breccias and dikes** in the following order:
Pyroxene-porphyrites, grading into **pyroxene- and hornblende-diorites** with biotite of final crystallization, with dikes of pyroxene- and hornblende-porphyrites, grading into	**Pyroxene-andesites**, breccia, and flows passing into
	pyroxene-hornblende-andesites, breccia, and flows, with dikes of similar andesites, grading into
hornblende-biotite-diorites with biotite of early crystallization, with dikes of hornblende-biotite-porphyrites;	**hornblende-biotite-andesites** in dikes, grading into
quartz-biotite-diorite-porphyrite with some hornblende, with dikes of quartz-biotite-porphyrite.	**dacites** with phenocrysts of quartz, biotite, and some hornblende.

The igneous rocks that formed the breccias and lava flows of Sepulchre Mountain with their dikes and larger intruded bodies constitute a series of andesites, basalts and dacites, which reach a degree of crystallization that places part of them among the porphyrites. They commenced with an andesitic breccia that is filled with Archean fragments, which must have been thrown from some neighboring center of eruption located in an Archean area. Such a center exists a few miles to the north. This was followed by a series of magmas that were at first somewhat basic and became more and more siliceous. The series is represented in the right hand column of Table XVI. From this it is seen that the succession of eruption in each locality was the same, after the first period, A, in which the magmas evidently came from different sources. Each series of the second period began with basic magmas and ended with acidic ones. Their division in the table into four groups is not intended to convey the idea that they belong to four distinct periods of eruption. The whole series in each case is more correctly a single, irregularly interrupted succession of outbursts of magma that gradually changed its composition and character. Upon comparing the rocks which have resulted from the corresponding phases of these series of eruptions, the similarity of the porphyritic forms is immediately recognized. The nature and distribution of the phenocrysts in the different varieties of andesite and dacite, which determine their macroscopical habit, have their exact counterpart in the different varieties of porphyrites. The microscopical characters of the phenocrysts in the corresponding varieties of porphyrites and of the intruded andesites and dacites are identical. The character of the various groundmasses, however, is different in the two groups, being more highly crystalline in the porphyrites—many of the andesites being glassy. Many of the finer grained diorites have a habit, derived from the distribution of the ferromagnesian silicates and larger feldspars, which resembles that of some of the andesites and dacites which correspond to them chemically.

Finally, the study of the chemical composition of the intrusive rocks of Electric Peak and of the volcanic rocks of Sepulchre Mountain proves that these two groups of rocks have identical chemical compositions, for the varieties that have been analyzed are but a few of the many mineralogical and structural modifications assumed by these magmas on cooling. The analyses serve as indications of the range of the chemical variability of these magmas.

From the geological structure of the region, then; from the correspondence between the order of eruption of the two series of rocks; from the resemblance of a large part of the rocks of both series, macroscopically and microscopically, and from the chemical identity of all the rocks of both groups, it is conclusively demonstrated that:

I. The volcanic rocks of Sepulchre Mountain and the intrusive rocks of Electric Peak were originally continuous geological bodies.

II. The former were forced through the conduit at Electric Peak during a series of more or less interrupted eruption.

III. The great amount of heat imparted to the surrounding rocks was due to the frequent passage of molten lava through this conduit.

We have, then, in this region the remnant of a volcano, which has been fractured across its conduit, has been faulted and considerably eroded; and which presents for investigation on the one hand, the lower portion of its accumulated debris of lavas, with a part of the upper end of the conduit filled with the final intrusions; and on the other hand, a section of the conduit within the sedimentary strata upon which the volcano was built.

CORRELATION OF THE ROCKS ON A CHEMICAL BASIS.

Correlating the two groups of rocks according to their chemical composition and arranging them as in Table XVII, we see that the hornblende-mica-andesites, Nos. 95 and 102, are the equivalents of the quartz-mica-diorites, Nos. 215, 213, 205, 227, and 223, and of the quartz-pyroxene-mica-diorite, No. 211. The dacites, Nos. 129, 131, are the equivalents of the quartz-mica-diorite-porphyrites, Nos. 233 and 230. The hornblende-pyroxene-andesites and the pyroxene-andesites, Nos. 33, 80, 20, 2, and 21, are the equivalents of the coarse grained pyroxene-mica-diorite, No. 197, with variable percentage of quartz, and of the fine grained diorites, Nos. 176 and 177, and of a fine grained facies, No. 171.

The dacites and hornblende-mica-andesites included within this correlation are intruded bodies within the breccia of Sepulchre Mountain, and have the same mineral composition as the corresponding porphyrites and diorites of Electric Peak. They differ from them in structure and degree of crystallization, the details of which have already been described in earlier parts of this paper.

The glassy andesite with pyroxene and hornblende phenocrysts, however, present the utmost contrast to the chemically equivalent, coarsely crystalline diorites. In the former the hypersthene, augite, hornblende and plagioclase are sharply defined, idiomorphic crystals in a groundmass of glass, which is crowded with microlites of plagioclase and pyroxene, besides grains of magnetite. The hornblende is brown, occasionally red, and the other phenocrysts have all the microscopical characters which distinguish their occurrence in glassy rocks. In the diorite the hornblende is green, in some cases brown; and the hypersthene, augite and hornblende are accompanied by biotite, and are all intergrown in the most intricate manner, with evidence that they commenced to crystallize in the order just given. The labradorite is often clouded with minute opaque particles, which are characteristic of its occurrence in many diorites; it is surrounded by a shell of more alkaline plagioclase, which with occasional individuals of orthoclase and considerable quartz, closed the crystallization of the magma. Magnetite, apatite and zircon are the accessory minerals. The quartz contains fluid inclusions, which complete the correspondence of this diorite with typical diorites of other regions.

From the structure of this region, which has been so finely exposed by faulting and erosion, it is evident that of the different magmas erupted a part found their way into vertical fissures and took the form of dikes; part reached the surface and became lava flows and breccias, while other portions remained in the conduit. Therefore the various portions of the magmas solidified under a variety of physical conditions, imposed by the different geological environment of each, the most strongly contrasted of which were the rapid cooling of the surface flows under very slight pressure, and the extremely slow cooling of the magmas remaining within the conduits under somewhat greater pressure.

TABLE XVII.—*Correlation of the two groups of rocks upon a chemical basis.*

SiO_2%.	No.	Volcanic rocks of Sepulchre Mountain.			Intrusive rocks of Electric Peak.	
		Name.	Essential minerals.		Name.	Essential minerals.
			Phenocrysts.	Groundmass.		
69.24	230	.....	.....	.....	quartz-mica-diorite-porphyrite.	quartz, biotite, plagioclase, and alkali feldspar, hornblende.
67.54	223	.....	.....	.....	quartz-mica-diorite	biotite, hornblende, plagioclase, (orthoclase), quartz.
67.49	131	dacite	quartz, biotite, hornblende, plagioclase.	holocrystalline, quartz, feldspar.		
66.05	227	.....	.....	.....	quartz-mica-diorite	biotite, hornblende, plagioclase, (orthoclase), quartz.
65.97	233	.....	.....	.....	quartz-mica-diorite-porphyrite.	biotite, hornblende, plagioclase, (orthoclase), quartz.
65.66	129	dacite	quartz, biotite, hornblende, plagioclase.	holocrystalline, quartz, feldspar.		
65.60	205	.....	.....	.....	quartz-mica-diorite	biotite, hornblende, (pyroxene), plagioclase, (orthoclase), quartz.
65.50	102	hornblende-mica-andesite.	hornblende, biotite, plagioclase.	holocrystalline, quartz, feldspar.		
65.11	213	.....	.....	.....	quartz-mica-diorite	biotite, hornblende, augite, hypersthene, plagioclase (orthoclase), quartz.
64.85	215	.....	.....	.....	quartz-mica-diorite	hornblende, biotite, plagioclase, (orthoclase), quartz.
64.27	95	hornblende-mica-andesite.	hornblende, biotite, plagioclase, magnetite.	holocrystalline, quartz, feldspar.		
64.07	211	.....	.....	.....	quartz-pyroxene-mica-diorite.	biotite, hornblende, augite, hypersthene, magnetite, plagioclase, (orthoclase), quartz.
61.22	176	.....	.....	.....	pyroxene-mica-diorite.	biotite, hornblende, augite, hypersthene, magnetite, plagioclase, (quartz).
60.30	21	hornblende-pyroxene-andesite.	hornblende, augite, hypersthene, plagioclase, magnetite.	glassy, microlitic.		
58.05	177	.....	.....	.....	pyroxene-mica-diorite	biotite, hornblende, augite, hypersthene, magnetite, plagioclase, (quartz).
57.38	171	.....	.....	.....	pyroxene-porphyrite	augite, hypersthene, biotite, magnetite, plagioclase, quartz.
57.17	2	pyroxene-andesite	augite, hypersthene, plagioclase.	brown glass, microlitic.		
56.61	20	hornblende-pyroxene-andesite.	hornblende, augite, hypersthene, plagioclase.	glassy, microlitic.		
56.28	197	.....	.....	.....	pyroxene-mica-diorite.	biotite, hornblende, augite, hypersthene, magnetite, plagioclase, quartz.
55.92	80	hornblende-andesite	hornblende, plagioclase	microcrystalline.		
55.83	33	pyroxene-andesite	augite, hypersthene, plagioclase.	glassy, microlitic.		

TABLE XVIII.—*Correlation of the grades of crystallization of the rocks from Sepulchre Mountain and Electric Peak.*

Grades of crystallization.	Sepulchre Mountain.																Electric Peak.														
	Breccias.					Dike rocks.											Dike rocks.											Stock rocks.			
	B_1.	B_2.	B_3.	B_4.	B_5.	D_1.	D_2.	D_3.	D_4.	D_5.	D_6.	D_7.	D_8.	D_9.	D_{10}.	D_{11}.	D_{12}.	d_1.	d_2.	d_3.	d_4.	d_5.	d_6.	d_7.	d_8.	d_9.	d_{10}.	d_{11}.	s_1.	s_2.	s_3.	s_4.
1		9, 10			28																										
2	1, 2, 3, 4	11, 12	14	18	29	33, 34, 35	39, 40																								
3	5, 6, 7, 8	13	15, 16	19, 20, 21, 22, 23, 24, 25.	30		41	43, 44, 45, 46.		68																					
4			17	26, 27.	31, 32				53	69, 70	83	85																			
5									54	71, 72			90, 91	104																	
6						36		47, 48, 49	55	73, 74		86	92, 93		106	116, 117												163				
7						37				75, 76, 77	84		94, 95		107	118, 119, 120,	131					144						164, 165				
8									56, 57, 58, 59.	78, 79, 80, 81.		87	96, 97, 98		108, 109, 110, 111.	121, 122, 123, 124, 125,	132, 133.				142						166, 167				
9									60, 61, 62, 63, 64.				99, 100	105	112	126. 127						145. 146				162	168, 169				
10																															
11									65, 66	82							134					147	150								
12								50				88, 89										148, 149			159, 160.						
13															113		135				143			153, 154	161						
14						38		51					101										151, 152	155, 156, 157				170				
15									67				102						139					158				171				
16																128												172				
17													103		114, 115	129, 130		136		140, 141								173				
18								52										137										174	203			
19																													204, 205			
20																													206	216, 217		
21																													207, 208			228, 229
22																													209			230, 231
23																																232, 233
24																												175				234, 235
25																												176				
26							42																					177, 178		218	236
27																		138												219	237
28																												179, 180			
29																												181	210		
30																												182			
31																												183			
32																												184, 185			
33																												186, 187			
34																												188			
35																												189, 190, 191.			
36																												192	211		
37																												193	212	220	238
38																												194	213	221	
39																														222, 223, 224.	
40																												195	214		
41																												196	215		
42																												197		225, 226, 227.	
43																												198			
44																												199			
45																												200			
																												201			
																												202			

The effect of this diversity of conditions upon the degree of crytallization of the various portions of these rocks is well shown in the accomnynying Table XVIII, which has been derived from Tables VIII and XIV.

In this table are presented all of the specimens from Sepulchre Mountain and Electric Peak. They are arranged in four principal divisions: First, the breccias and lava flows; second, dikes and larger bodies intruded in these breccias; third, dikes in the Cretaceous strata of Electric Peak; fourth, the main stock and its immediate apophyses. These groups are still further subdivided into columns which correspond to mineralogical differences in the rocks, and bear the same letters as the mineralogical subdivisions in Tables III, VIII, XII, and XIII. Consequently each of the four principal groups has the most basic members at the extreme left and the most acidic ones at the extreme right. The mineralogical range is, therefore, repeated four times. The table illustrates a number of facts. It exhibits the relative degree of crystallization of the breccias, lava flows, dikes, and stock rocks, and shows that a great number of intermediate steps can be recognized between the most glassy andesite and the coarsest diorite. It shows that the dike rocks furnish the connecting link between these two extremes, and that the dike rocks of Electric Peak have the same range of grain as the majority of those of Sepulchre Mountain. But many of those at Sepulchre Mountain are still finer grained and some are glassy, being vesicular also. Between these rocks there is the closest possible resemblance macroscopically, and the two groups might have been described conjointly so far as their petrographical characters were concerned. The variation of grain within each of the four principal divisions is very significant when taken in connection with the geological occurrence of the different rocks. The limited range of variation in the first group is in accord with the fact that all of these rocks are surface ejectamenta. The range in the third group from more crystalline basic rocks to less crystalline acid rocks, as already pointed out on page 621, shows the greater tendency of the basic rocks to crystallize. And since the dikes here represented are nearly the same size, this variation of grain corresponds to differences in the chemical composition of the rocks. On the contrary the variations in the second group indicate a slightly greater crystallization of the acid rocks. This, however, is due to the fact that the basic rocks in this group, with a few exceptions, occur in small dikes, while the acid rocks for the most part form broad intruded bodies a number of hundred feet wide. In these cases the size of the mass has had more influence on the degree of crystallization than the chemical composition of the magma has had. In the fourth group the basic rocks exhibit a wider range of grain than the acidic, being much coarser and also considerably finer grained than the latter. This arises from the fact that the basic rocks form a much larger mass and exhibit great variation of grain, having fine grained facies that have been fully discussed in an earlier part of this paper.

These Tertiary diorites and others that cut the volcanic lavas in several localities in this region correspond to the *andesdiorites* and *andesgranites* of Stelzner, who described stocks of granular rocks penetrating the andesitic tuffs in the Argentine Republic. The study of these Tertiary granular rocks led him to the conclusion that the degree of crystallization of eruptive rocks is in no way dependent on their age, but depends on the physical conditions under which the mineralogical differentiation and the cooling of the magma took place.[1]

From the study and comparison of the chemical analyses of the two groups of rocks under investigation it is demonstrated that the magmas that reached the surface of the earth in this place had exactly the same chemical composition as those which remained inclosed within the sedimentary strata. It proves with equal clearness that the different conditions attending the final consolidation of the ejected and of the intruded magmas affected *not only their crystalline structure, but their essential mineral composition.* The most marked illustration of this is in the occurrence of biotite in the two series. In the volcanic rocks of this locality biotite is an essential constituent of the more siliceous varieties, and is only rarely found as an accessory constituent of the varieties with less than 61 per cent of silica. In the intrusive rocks it is an essential constituent of all the coarse grained varieties, even the most basic. In the finer grained porphyritic forms it is a constituent of the groundmass to a variable extent. The second most noticeable difference is the presence of considerable quartz in the coarse grained forms of the basic magma and its absence from the volcanic forms of the same magmas.

From these observations, then, we see that in this region there are chemically identical rocks which have distinctly different mineral compositions, but which were once parts of a continuous body of molten magma. We are led, therefore, to the conclusion that—

The molecules in a chemically homogeneous fluid magma combine in various ways, and form quite different associations of silicate minerals, producing mineralogically different rocks.[2]

The bearing of these facts upon the question of the classification of igneous rocks is that, since different portions of a large body of a chemically uniform magma may assume a variety of geological forms within

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[1] Alfred Stelzner: Beiträge zur Geologie und Paleontologie der Argentinischen Republik. Cassel and Berlin, 1885, p. 207.

"Sie (die Andengesteine) wird uns, wie ich meinerseits glaube, immer mehr und mehr erkennen lassen, dass die grössere oder geringere Krystallinität eruptiver Gesteine keineswegs, wie man so lange und so hartnäckig behauptet hat, von dem Alter der letzteren abhängig ist, sondern lediglich von den physikalischen Umständen, unter denen die mineralische Differenzirung und Erkaltung der gluthflüssigen Magmen vor sich ging."

[2] This conclusion is the same as that stated by Justus Roth:

"Es können mineralogisch ganz verschiedene Gesteine in dieselbe Gruppe gehören, denn *feurigflüssige Massen von gleicher oder sehr nahe gleicher chemischer Zusammensetzung können in verschiedene Mineralien auseinanderfallen.* Die Ursachen, welche diese Erscheinung bedingen, lassen sich höchstens muthmassen und mögen in Unterschieden des Druckes, der Temperatur, des umgebenden Mediums der Unterlage u. s. w. gesucht werden." Die Gesteins-Analysen in tabellarischer Übersicht und mit kritischen Erläuterungen. Berlin, 1861. p. XXI.

the earth's crust or upon its surface and may crystallize into rocks with different mineral composition, it is more proper to consider intrusive and effusive rocks that have like chemical composition as *corresponding* or *equivalent* rocks than those forms of the two series that have similar mineral composition. Thus we would not say that certain volcanic rocks which are the *equivalents* of certain intrusive ones differ from them chemically by such and such variations among the oxides, for the term *equivalent* would then simply refer to their mineralogical character, and we might be comparing portions of totally different magmas that had no geological connection with one another. Used in the other sense, we should say that certain volcanic rocks differ from their *corresponding* or *equivalent* intrusive rocks by the presence or absence of certain minerals, and in this way we would be grouping together the extrusive and intrusive portions of the same body of magma. The classification would then rest on a common geological and chemical basis.

In this region of Electric Peak and Sepulchre Mountain the greatest mineralogical differences accompany the greatest differences in structure or degree of crystallization; hence we may assume that the causes leading to each are coexistent. The source of these causes must be sought in the differences of geological environment, and these affect the rate at which the heat escapes from the magmas and the pressure they experience during crystallization.

It is to be remarked that the most essential mineralogical difference between the intruded rocks and their chemically equivalent extrusive forms is the much greater development of biotite and quartz in the intruded rocks; these minerals being abundant even in the basic intrusions and absent from their basic volcanic equivalents. That their simultaneous development is naturally to be expected in many cases is evident from a consideration of the character of their chemical molecules and that of other minerals common to these rocks. For if we assume that biotite is made up of two molecules, K and M, corresponding respectively to $K_6Al_6Si_6O_{24}$ and $R_{12}Si_6O_{24}$, and compare these with the molecules of orthoclase, $K_2Al_2Si_6O_{16}$, of olivine, R_2SiO_4, and of hypersthene $RSiO_3$, we see that molecules which under some conditions might have taken the form of olivine or hypersthene and potash-feldspar, which latter may have entered into combination with lime-soda feldspar molecules to form somewhat alkaline feldspars, may under other conditions combine as biotite with the separation of free silica or quartz; in which case also the feldspars of the rock would be less alkaline.

Another mineralogical difference between the two groups of rocks just mentioned is the greater development of hornblende in the intruded rocks in place of augite, which is chemically its equivalent, though it has not been determined whether in this case the hornblende of the diorite has precisely the same composition as the augite of the andesite. The probability is that there are slight differences between them.

EFFECT OF MINERALIZING AGENTS.

The crystallization of quartz, biotite, and hornblende in fused magmas, according to our present knowledge, requires the assistance of a mineralizing agent; for it has been demonstrated by synthetical research that these minerals will not crystallize into the forms they assume in igneous rocks when their chemical constituents are fused and simply allowed to cool under ordinary atmospheric conditions. But they have been produced artificially with the aid of the mineralizing action of water and other vapors. Now there is ample evidence both in the ejected lavas and in the coarsely crystallized rocks in the conduit that water vapor was uniformly and generally distributed through the whole series of molten magmas, and there is no evidence that there existed in the magmas which stopped within the conduit any more or different vapors than those which existed in the magmas that reached the surface. Hence we conclude that:

The efficacy of these absorbed vapors as mineralizing agents was increased by the conditions attending the solidification of the magmas within the conduit.

Moreover, if it is necessary, as advocated by the French geologists, MM. Michel Lévy,[1] de Lapparent[2] and others, to refer the crystallization of certain minerals, as quartz, to the mineralizing influence of absorbed vapors, it is evident that the required mineralizing agent is universally present in sufficient quantities, since there are no instances where a magma of the requisite chemical composition has failed to crystallize completely with the development of quartz when subjected to the proper physical conditions.

However, it is probable that differences in the amount or in the kind of mineralizing agents produce differences in the degree or nature of the crystallization of similar magmas which have solidified with the same geological environment.

It has been suggested by Dr. H. J. Johnston-Lavis[3] that the nature of the rocks surrounding a conduit through which molten magmas pass materially affects the amount and character of the vapors introduced into these magmas, which will vary as the surrounding rocks are more or less porous and are saturated with different kinds of waters. The effect of these vapors on the structure and composition of igneous rocks is also discussed by the same writer.

The effect of differences in the amount of the mineralizer in a single magma is well illustrated in the structure of the obsidian at Obsidian Cliff, Yellowstone National Park,[4] where the alternating layers of

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[1] "Structures et Classification des Roches Éruptives." Paris, 1889, pp. 5 and 12.

[2] Revue des Questions Scientifiques. Paris, 1888, p. 36.

[3] "The Relationship of the Structure of Rocks to the Conditions of their Formation." Sci. Proc. of the Royal Dublin Soc., vol. 5 (n. s.), part 3, July, 1886, pp. 113 to 155.

[4] Obsidian Cliff, Yellowstone National Park, by J. P. Iddings. Seventh Annual Report of the Director of the U. S. Geological Survey, Washington, D. C., 1888, p. 287.

holocrystalline and glassy rock appear to be unquestionably due to the irregular distribution through the magma of vapors, which in the upper portion of the flow have produced alternating layers of pumice and compact glass. The mineralizing agent was present, however, in the alternate glassy layers as well as in the crystallized or in the pumiceous ones, for in the highest portion of the flow the whole mass is pumiceous but in different degrees, and the presence of absorbed vapors may be detected chemically and physically in the compact layers. Its amount, however, was not sufficient to produce complete crystallization under the attendant physical conditions. Its effectiveness in this case was controlled by the geological occurrence of the magma.

It is to be observed, in addition, that whatever the mineralizing vapors in acidic magmas may be, there is the same evidence of their existence in intermediate and in basic magmas, whether we investigate them chemically or physically, or study the phenomena of their geological occurrence. There are even indications of their greater abundance in the basic lavas, many of whose glasses contain a high percentage of water, and the highly vesicular character of whose lava-flows is universal. Nor are the geological evidences less conclusive that demonstrate the existence of abundant explosive agents in the basaltic and andesitic magmas that have hurled their shattered masses over broad areas of country, and have piled vast accumulations of basaltic breccia throughout our western territory.

Nevertheless, with all these evidences of the universal presence of mineralizing agents in basic magmas, we do not recognize their influence upon the microstructure or crystallization of basic lavas. We may assume, then, that in the majority of these cases they have no influence.

But when the basic magmas become coarsely crystalline, and separate into minerals, the cystallization of some of which we have already referred to the action of mineralizing vapors, we may logically assume that in these cases the absorbed vapors have influenced the crystallization of the magmas.

If this reasoning is correct, then the action of mineralizers upon basic magmas is controlled by the physical conditions under which they solidify.

Finally, if mineralizing agents are universally present in igneous magmas, and if their action, so far as we can observe it, is controlled by the physical conditions imposed by the geological history of each eruption, we should not regard the presence or absence of certain minerals, relegated to the influence of mineralizing agents, as evidence of the presence or absence of these agents in the molten magma; but we should see in it the evidence of special conditions controlling the solidification of the magma, and should seek the fundamental causes of the mineralogical and structural variations of a rock in the geological history of its particular eruption.

APPLICATION TO THE CLASSIFICATION OF IGNEOUS ROCKS.

The facts brought out by the study of this occurrence of igneous rocks seem to the writer to have a direct application to the problem of the general classification and description of igneous rocks. For while this occurrence cannot be regarded as a representative of all others, still it typifies to a very great extent the relations that exist between intruded magmas and their extrusive forms.

We have observed that in this locality a series of molten magmas was erupted through a common conduit during a succession of fracturings of the sedimentary strata. These magmas not only differed among themselves chemically, but varied somewhat in different portions of one and the same body, producing chemical facies of the main body of a particular rock mass.

When we consider the variations in the chemical composition and structure, and mineral constitution of a continuous geological body, such as may occur along an irregularly shaped crevice or system of fissures from their narrow and remote terminations toward their wider junctions with the main conduit, as well as the interpenetration and welding of older and newer portions of the magmas filling the conduit, with their consequent transitions in some places, and sharply marked intersections or contacts in others, we see that the resulting mass of igneous rocks presents a geological body whose complexity exceeds that of the most intricate web of vegetable organism.

Chemically considered there is a wide range of composition embracing the middle of the whole series of igneous rocks of the surrounding region. In percentage of silica they range from 53 per cent to 69 per cent; and if certain contemporaneous intruded rocks in the immediate neighborhood be included, the range of variation in the intrusive rocks is about the same as that of the volcanic rocks, from 48 per cent to 74 per cent.

Structurally, there are all forms from coarsely granular to porphyritic glassy, including all possible intermediate structures.

Mineralogically, there are all the combinations existing in this region, from that of quartz, alkali-feldspar, and mica, to that of basic lime-soda-feldspar and pyroxene, with a little olivine.

Hence the rocks include granite, granite-porphyry, quartz-porphyry, and rhyolite; diorite, quartz-mica-diorite, diorite-porphyrite, pyroxene-porphyrite, hornblende-mica-andesite, hornblende-andesite, pyroxene-andesite, dacite, and basalt. The glassy form of the granite-porphyry or of the quartz-diorite-porphyrite is not found in the immediate vicinity of Sepulchre Mountain, but occurs in the region south as a modification of the rhyolite at the Upper Geyser Basin. The still more siliceous rhyolite of Sepulchre Mountain is represented by a facies of the microgranite at Echo Peak, a point 12 miles south of Electric Peak.

Notwithstanding the range of structural variations within the mineralogical groups just mentioned, it is not possible to trace in exposure

any one group through this series of structural variations. It becomes evident that while a perfectly continuous body may, and undoubtedly does in some instances, connect the glassy form of a consolidated magma with a coarsely granular form through intermediate stages of crystalline structure, yet the connected occurrence of all these forms is not a necessity, and in fact does not always exist. For if we consider the course of eruption of a magma that varies in its chemical composition, or the successive outbursts of a series of magmas that differ chemically from one another, we see that if a basic magma which has reached the surface of the earth and has produced glassy rocks—andesites—and has filled the disrupted strata with intruded sheets and dikes of porphyrite, and stands in the conduit under conditions which would eventually produce coarse grained diorite—if a basic magma in this stage of solidification be followed through the same conduit by a more siliceous magma, then the viscous body within the conduit would be forced out on the surface and its place occupied by the later magma, which would thus sever the connection between the intruded sheets or dikes and the surface lavas, and would deprive both of a coarse grained equivalent. Moreover, it is well known that in volcanic regions it usually happens that the lava that flows from a cone severs its connection with the molten magma in the crater, which often descends again within the conduit.

In the case of a great body of magma which varied in composition during a prolonged eruption, so that the first portion of it differed considerably from the last portion, the surface flows and earliest intrusions, if continuously connected with the deep-seated portion, would grade into it not only through a variety of structural modifications, but through a series of chemical and mineralogical variations, so that their actual geological connection would be with a coarse grained rock of a different type.

Furthermore, the magmas, which can be recognized at this locality as having constituted independent eruptions, not only differ in their chemical composition from one another, but vary to such an extent within their own mass that the chemical facies of one body correspond to the main portion of another. Hence the members of the series overlap one another in composition. Consequently a classification or consideration of the various forms of rocks of the same chemical composition involves in this case the artificial grouping of parts and facies of different geological bodies.

In the study and discussion of the igneous rocks of this region it has been found that the natural and most intimate grouping of the rocks brings together varieties of the surface or extrusive rocks which differ chemically, mineralogically, and to a certain extent structurally. In another group it brings together varieties of coarse grained rocks which vary chemically, mineralogically, and to a certain extent structurally. And in another group it presents a collection of intruded

sheets and dikes, with similar chemical and mineralogical variations, and another range of structural variations. The distinction between these groups is the range of the structural variations in each, which is coupled with their mode of occurrence. But here also is an overlapping of the groups, there being no sharp line between the first and second, or between the second and third. This, however, is not so much of an objection to the treatment of the subject as that which would follow a grouping upon a chemical basis, for the latter would still leave unreconciled the mineralogical variations that are dependent on the mode of occurrence. It is this complicated relationship which has rendered a clear and comprehensive description of the occurrences so difficult.

Since this complication of relationships between all varieties of igneous rocks exists universally, as it has been shown to exist at Electric Peak and Sepulchre Mountain; and since the classification of igneous rocks along any single line of relationship can not be a simple and at the same time a natural one, it seems to the writer that the most satisfactory treatment of the subject brings together into groups for purposes of description rocks of similar or allied structures, but of various mineral and chemical compositions.

This grouping appears the more rational when it is considered that the chemical variability of rock magmas which leads to the formation of local modifications of rocks or to their chemical facies is, as the writer believes and hopes to be able to demonstrate at another time, the underlying principle which gives rise to the chemical differences among the rocks themselves. In other words, the chemical differences of igneous rocks are the result of a chemical differentiation of a general magma. And in a very special manner all of the igneous rocks of any locality are so intimately related to one another chemically that there is far more reason for considering them as a complex chemical unit than as a number of independent, well defined magmas.

It is to be remarked, moreover, that if, as demonstrated in this paper, the conditions attending or controlling the crystallization of igneous magmas, whether affecting simply the rate of cooling, or acting through the medium of a mineralizing agent within the magma itself—if these conditions determine the species and character of the minerals developed, as well as the crystalline structure of the rock, then the grouping together of rocks of allied structures unites those rocks in which the mineralogical characteristics bear a certain relation to the chemical composition, which relation is different from that which exists in rocks that have crystallized under different conditions. There is, therefore, in such a grouping more than the similarity of structure or the geological association of the rocks in the field.

While the grouping of igneous rocks on a basis of crystalline structure, which would bring together coarse grained forms, medium grained forms, and extremely fine grained and glassy ones, is in a very large measure equivalent to classifying them on a geological basis, still the

precise connection between the crystalline structure and geological occurrence of all igneous rocks is not so uniform that it can be expressed in simple terms.[1] It is not, in fact, the particular mode of occurrence of a rock, geologically considered, that determines its structure, but the physical conditions attending its eruption and solidification. And since these physical conditions may be occasioned by somewhat different geological circumstances, the resulting similar structures may be found with different geological environment. That is, a large mass of magma deep within the earth's crust may attain a crystalline character through the cooling of so large an inclosed mass, which may be more closely related, if not identical, to the crystallization of a much smaller mass that has solidified within highly heated rock walls, than it is to the structure of an equally large mass that has been chilled by being forced a longer distance through colder rocks, or that has solidified on the surface of the earth. As another example, narrow bodies of magma which have solidified at very much the same distance from the surface of the earth differ widely in their crystalline structure, according to the temperature of the rocks surrounding them at the time of their consolidation.

Recognizing, then, the intricacies of these geological and physical relations, it seems to the writer advisable to base the classification of igneous rocks on that character which may be determined with certainty from the rocks themselves, namely, the crystalline structure, and which, at the same time, is to so high a degree an exponent both of the chemical composition of the magmas and of the physical and geological conditions attending their solidification.

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[1] Compare in this connection the conclusions of M. Michel Lévy: "Ainsi, en résumé, les conditions de gisement nous paraissent en relations trop complexes avec les facteurs de la cristallisation pour pouvoir être substituées, comme entrée de classification, à la notion plus précise et toujours présente de la structure des roches."—Structures et Classification des Roches Éruptives. Paris, 1889, p. 10.

APPENDIX.

Owing to the fact that the specimens from Electric Peak and Sepulchre Mountain, which have been described in this paper, were collected at various times during a number of years in which these localities were visited, and consequently occur in widely separated parts of the original collection of rocks from the Yellowstone National Park, they bear numbers which range from 2 to 3,910. The use of these numbers tends to confuse the reader, and a new series of consecutive numbers has been substituted for them in this paper. Since the new series has no existence in actual fact, it is deemed advisable to publish a list of the original numbers with their new equivalents, in order that the work bestowed on this study may be followed up or reviewed by anyone wishing to investigate the subject for his own purposes. The catalogue referred to is given in Table XIX.

TABLE XIX.—*Original collection numbers of the specimens described in this paper.*

New.	Field.	New.	Field.	New.	Field.	New.	Field.	New.	Field.
Nos.	*Nos.*	*Nos.*	*Nos.*	*Nos.*	*Nos.*	*Nos.*	*Nos.*	*Nos.*	*Nos.*
1	3870	49	3858	97	226	145	2732	193	2680*e*
2	221	50	3855	98	3896	146	2720	194	2672
3	3891	51	3889	99	695	147	3205	195	3194
4	323	52	3906	100	3013	148	2725	196	2661
5	3871	53	3883	101	2739	149	2726	197	2669
6	321	54	3860	102	394	150	2711	198	2675
7	332	55	1385*b*	103	3014	151	2714	199	2702
8	3687	56	1385*a*	104	3701	152	2716	200	2686
9	3857	57	3866	105	3899	153	2659	201	3006
10	322	58	3694	106	3854	154	2713	202	3012
11	324	59	3892	107	3881	155	3206	203	2728
12	3	60	3861	108	3015	156	647	204	2704
13	3879	61	3862	109	2737	157	2666	205	2695
14	3872	62	3018	110	3686	158	3208	206	2703
15	395	63	3856	111	3897	159	2746	207	2685
16	3874	64	325	112	1386	160	2747	208	2715
17	392	65	2738	113	2741	161	2705	209	3011
18	3189*a*	66	2743	114	3019	162	2261	210	2682
19	213	67	3685	115	3842	163	2697	211	2681
20	214	68	3695	116	2744	164	2699	212	2727
21	217	69	696	117	3903	165	2698	213	2724
22	3691	70	3690	118	2745	166	2710*b*	214	2729
23	3697	71	3886	119	3904	167	2709	215	3008
24	3869	72	3689	120	3905	168	2710*a*	216	3224*a*
25	3890	73	3898	121	2742	169	2718	217	3224*b*
26	3679	74	3688	122	3678	170	3192	218	3224*c*
27	3698	75	3864	123	3910	171	2679	219	2722
28	218	76	3882	124	3682	172	3193*a*	220	2723
29	3693	77	3884	125	3683	173	3193*b*	221	2730
30	3846	78	3844	126	701	174	3193*c*	222	3222
31	2	79	3843	127	3850	175	3193*d*	223	2676
32	3696	80	694	128	3684	176	2673	224	3199′
33	219	81	209	129	3017	177	2692	225	3198
34	220	82	3020	130	3021	178	2735	226	3195
35	3876	83	3692	131	3682	179	3198′	227	2668
36	3875	84	3852	132	3022	180	2693	228	2672
37	215	85	3700	133	3851	181	2680*a*	229	2662
38	210	86	3849	134	3848	182	2680*b*	230	2670
39	212	87	3865	135	3016	183	3193*e*	231	2671
40	3895	88	3908	136	2734	184	3191	232	2749
41	3887	89	3699	137	2733	185	2680*c*	233	3001
42	2740	90	3902	138	3209	186	2684	234	3003
43	3888	91	3900	139	3009	187	2694	235	3004
44	3894	92	3847	140	2708	188	2680*d*	236	3002
45	3880	93	3189*b*	141	2717	189	2674	237	3007
46	3893	94	3878	142	2665	190	3199	238	2667
47	3885	95	2736	143	2260	191	3193*f*		
48	3877	96	211	144	3221	192	3190		

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U.S. GEOLOGICAL SURVEY.

110°30

110°50

45°

Electric Peak
11100

Gardiner River

ERUPTIVE ROCKS.

- t — Talus or Slide rock.
- r — Rhyolite.
- da — Dacite in dikes.
- m — Hornblende-mica-andesite in dikes.
- ha — Hornblende-and pyroxene-andesite in dikes.
- b — Hornblende-and pyroxene-andesite breccia and flows.
- a — Acidic andesitic breccia.
- p — Porphyrite in sheets.
- h — Hornblende-mica-porphyrite in dikes.
- q — Quartz-mica-diorite-porphyrite and quartz-porphyrite.
- d — Diorite and pyroxene-porphyrite.
- K — Cretaceous.
- J — Jura-Trias.
- C — Carboniferous.

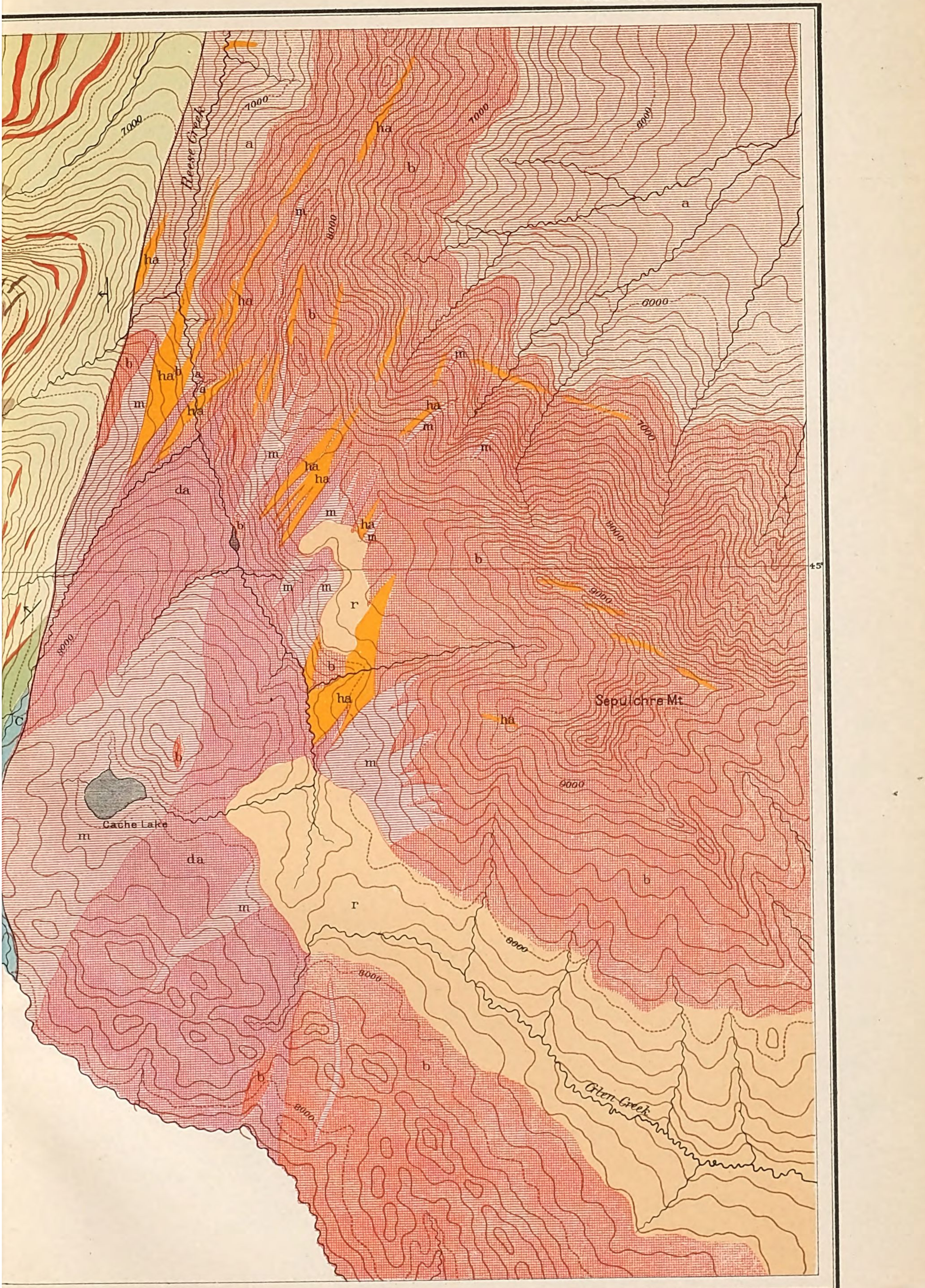
GEOLOGICAL MAP OF ELECTRIC PEAK AND SEPULCHRE MOUNTAIN. YELLOWSTONE NATIONAL PARK.

Geology by the members of the Yellowstone Park Division.
Arnold Hague, Geologist in Charge.

Scale 1 mile = 2 inches.

0 — ¼ — ½ — ¾ — 1 MILE.

CONTOUR INTERVAL 100 FEET.



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Iddings, Joseph Paxson

The Eruptive Rocks of Electric Peak and Sepulchre Mountain, Yellowstone National Park By Joseph Paxson Iddings

[s.l.] (1896)

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